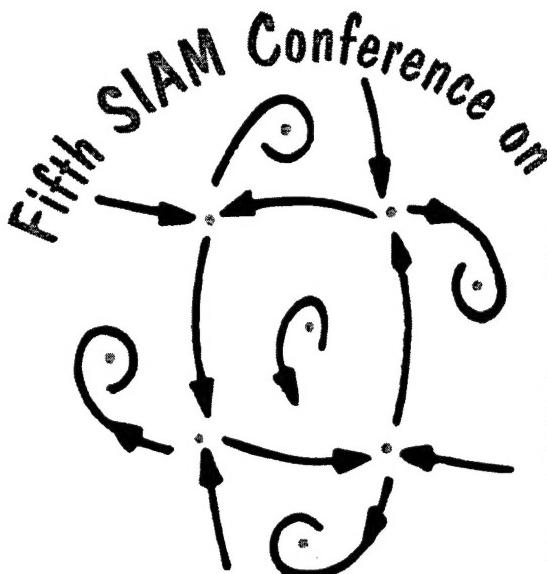


# Final Program and Abstracts

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## APPLICATIONS of DYNAMICAL SYSTEMS

May 23-27, 1999

Snowbird Ski and Summer Resort • Snowbird, Utah

Sponsored by SIAM Activity Group on Dynamical Systems

### Conference Themes

The themes of the 1999 conference include, but are not limited to

#### Principal Themes:

- Recent advances in the theory of nonlinear PDEs
- Orbital dynamics and space mission design
- Industrial mathematics: computational issues and modeling
- Molecular dynamics and DNA coding
- Ergodic theory and nonequilibrium statistical mechanics
- Data analysis, prediction and control

#### Applications in:

- Granular media
- Polymer flows
- Solid mechanics
- Oceanography and geophysical flows
- Biochemistry and biomolecular models

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[www.siam.org/meetings/ds99/](http://www.siam.org/meetings/ds99/)

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Society for Industrial and Applied Mathematics

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## Organizing Committee

**Emily Stone**, Chair  
Department of Mathematics and Statistics, Utah State University

**Dieter Armbruster**, Co-chair  
Department of Mathematics, Arizona State University

**Peter Bates**  
Department of Mathematics, Brigham Young University

**Shui Nee Chow**  
School of Mathematics, Georgia Institute of Technology

**Raymond Goldstein**  
Department of Physics, University of Arizona

**Jack K. Hale**  
School of Mathematics, Georgia Institute of Technology

**Jerrold Marsden**  
Control and Dynamical Systems, California Institute of Technology

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**Mary Silber**  
Engineering Sciences and Applied Mathematics, Northwestern University

**Steven H. Strogatz**  
Theoretical and Applied Mechanics, Cornell University

**James A. Yorke**  
Institute of Physical Science and Technology, University of Maryland, College Park

## Get-Togethers

**Welcoming Reception**  
6:00 PM-8:00 PM, Saturday, May 22  
Ballrooms I, II, and III

**SIAG/DS Business Meeting**  
5:00 PM-6:00 PM, Monday, May 24  
Ballroom I

**Poster Session and Dessert Reception**  
8:00 PM-10:00 PM, Wednesday, May 26  
Ballrooms I, II, and III

## About the Conference

The application of dynamical systems theory to areas outside of mathematics has proven to be an exciting and fruitful endeavor. The applications are highly diverse and interdisciplinary, ranging over such fields as Physics, Biology and Ecology, Engineering, Finance, Industrial Mathematics, Chemistry, Biochemistry and Genetics.

This conference strives to achieve an exciting mixture of applications and mathematics. The goals of the conference are a cross-fertilization between the different fields of the applications, and increased communication between the mathematicians who build the theory, and the scientists who use it.

## Funding Agency

SIAM and the Conference Organizing Committee wish to extend their thanks and appreciation to the Office of Naval Research for its support of this conference.

# **Program-At-A-Glance**

Quick Guide to  
Dynamical Systems  
Conference 1999

**OPEN HERE**



## **Program-At-A-Glance**

Fifth SIAM Conference on Applications  
of Dynamical Systems

**Saturday, May 22 and  
Sunday, May 23**

Monday  
May 24

**Tuesday**  
**May 25**

<b>7:00 PM-7:30 PM</b>	Registration opens <i>Ballroom Lobby</i>	<b>7:30 AM-4:00 PM</b>	Registration opens <i>Ballroom Lobby</i>	<b>7:30 AM-4:00 PM</b>	Registration opens <i>Ballroom Lobby</i>
<b>6:00 PM-8:00 PM</b>	Welcoming Reception <i>Ballrooms I, II, and III</i>	<b>8:30 AM-9:30 AM</b>	IP3 Dynamics of Microstructure/Flow Interactions <i>M. Gregory Forest</i> <i>Ballrooms I, II, and III</i>	<b>8:30 AM-9:30 AM</b>	IP5 Attractors in Evolutionary Equations <i>Jack Hale</i> <i>Ballrooms I, II, and III</i>
<b>7:30 AM-4:00 PM</b>	Registration opens <i>Ballroom Lobby</i>	<b>9:30 AM-10:00 AM</b>	Coffee <i>Ballroom Lobby</i>	<b>9:30 AM-10:00 AM</b>	Coffee <i>Ballroom Lobby</i>
<b>8:15 AM-8:30 AM</b>	Welcoming Remarks <i>Emily Stone and Dieter Armbruster</i> <i>Ballrooms I, II, and III</i>	<b>10:00 AM-12:00 PM</b>	MS11 Chaos and Communication • <i>Ballroom I</i> MS12 Applied Topology in Dynamics • <i>Ballroom II</i>	<b>10:00 AM-12:00 PM</b>	MS26 Embeddings and Control — Part II of II • <i>Ballroom I</i>
<b>8:30 AM-9:30 AM</b>	IP1 Diffraction of Atoms by Real, Complex and Imaginary Crystals of Light <i>Sir Michael Berry</i> <i>Ballrooms I, II, and III</i>	MS13 Dynamical Data Analysis in Biology • <i>Ballroom III</i> MS14 Characterization of Spatiotemporal Chaos • <i>Magpie A/B</i>	MS27 Vibrating Granular Media • <i>Ballroom II</i> MS28 Nonlinear Advection Diffusion Equations • <i>Ballroom III</i>	<b>MS29 Bifurcations in Neuron Dynamics • Magpie A/B</b>	<b>MS30 Invariant Manifolds, Foliations and Applications • Wasatch A/B</b>
<b>9:30 AM-10:00 AM</b>	Coffee <i>Ballroom Lobby</i>	MS15 Nonlinear Dynamics of Partial Differential Evolution Equations and Applications • <i>Wasatch A/B</i> MS16 Numerical Analysis of Contact Problems Involving Friction • <i>Golden Cliff</i> MS17 Analysis and Computation of Bistable Differential Equations • <i>Maybird</i>	MS31 Nonlinear Dynamics in Communication • <i>Golden Cliff</i> MS32 Observation, Analysis and Modeling of Excitable Systems • <i>Maybird</i>	<b>MS33 Pattern Formation in the Cahn-Hilliard Model — Part I of II • Superior A</b>	<b>MS34 New Models &amp; Analysis of Noise-Sensitive Systems • Superior B</b>
<b>10:00 AM-12:00 PM</b>	MS1 Differential Delay Equations • <i>Ballroom I</i> MS2 Synchronous Chaos and Invariant Manifolds • <i>Ballroom II</i> MS3 Coping with Nonstationarity in Time Series Data • <i>Ballroom III</i>	MS18 Nonlinear Evolution, Separatrix Splitting, and Chaos in Dynamical Systems • <i>Superior A</i> MS19 Flows of Liquid Crystalline Polymers • <i>Superior B</i> MS20 Stability and Bifurcations of Relative Equilibria: Theory • <i>White Pine</i>	MS35 Stability and Bifurcations of Relative Equilibria: Applications • <i>White Pine</i>	<b>12:00 PM-1:30 PM</b>	Lunch Attendees are on their own.
<b>12:00 PM-1:30 PM</b>	Lunch Attendees are on their own.	<b>12:00 PM-1:30 PM</b>	Lunch Attendees are on their own.	<b>1:30 PM-2:30 PM</b>	IP6 Finite Element Analysis of Nonsmooth Contact <i>Michael Ortiz</i> <i>Ballrooms I, II, and III</i>
<b>1:30 PM-2:30 PM</b>	IP2 Analysis of a Class of Strange Attractors <i>Lai-Sang Young</i> <i>Ballrooms I, II, and III</i>	<b>1:30 PM-2:30 PM</b>	IP4 Life at the Boundary of Chaos Theory and Nonequilibrium Statistical Mechanics <i>J. Robert Dorfman</i> <i>Ballrooms I, II, and III</i>	<b>2:30 PM-3:00 PM</b>	Coffee <i>Ballroom Lobby</i>
<b>2:30 PM-3:00 PM</b>	Coffee <i>Ballroom Lobby</i>	<b>2:30 PM-3:00 PM</b>	Coffee <i>Ballroom Lobby</i>	<b>3:00 PM-5:00 PM</b>	CP15 Data Analysis I and Spatiotemporal • <i>Ballroom I</i>
<b>3:00 PM-5:00 PM</b>	CP1 Neurons • <i>Ballroom I</i> CP2 Fluids • <i>Ballroom II</i> CP3 Communication • <i>Ballroom III</i> CP4 Applications I • <i>Magpie A/B</i> CP5 Bifurcations with Symmetry • <i>Wasatch A/B</i> CP6 Nonlinear Optics • <i>Golden Cliff</i> CP7 Homoclinic Dynamics • <i>Maybird</i> CP8 Materials • <i>Superior A</i> CP9 Bifurcations in Nonsmooth Systems • <i>Superior B</i>	MS21 Embeddings and Control — Part I of II • <i>Ballroom I</i> MS22 Networks of Oscillators • <i>Ballroom II</i> MS23 Mathematical and Computational Issues in Dynamics and Turbulence • <i>Ballroom III</i> MS24 Qualitative Analysis of Nonlinear Partial Differential Equations • <i>Superior A</i> MS25 Chaos and Irreversibility • <i>Maybird</i> CP10 Geophysical Flows • <i>Magpie A/B</i> CP11 Granular Flows • <i>Wasatch A/B</i> CP12 Physiology • <i>Superior B</i> CP13 Delay Equations • <i>Golden Cliff</i> CP14 Hamiltonian Systems • <i>White Pine</i>	CP16 Mathematical Biology I • <i>Ballroom II</i> CP17 Coupled Oscillators I • <i>Ballroom III</i> CP18 Patterns I • Anisotropic • <i>Magpie A/B</i> CP19 Control I • <i>Wasatch A/B</i> CP20 Chaotic Maps I • <i>Golden Cliff</i> CP21 Solitons I • <i>Maybird</i> CP22 Numerics I • <i>Superior A</i> CP23 Transport I • <i>Superior B</i> CP24 PDEs I • <i>White Pine</i>	<b>5:30 PM-7:00 PM</b>	Dinner Attendees are on their own.
<b>5:00 PM-7:00 PM</b>	Dinner Attendees are on their own.	<b>5:00 PM-6:00 PM</b>	Business Meeting: SIAG/DS <i>Ballroom I</i>	<b>7:30 PM-9:30 PM</b>	Concurrent Sessions
<b>6:00 PM</b>	Dinner Attendees are on their own.	<b>6:00 PM</b>	Dinner Attendees are on their own.	CP25 Data Analysis II • <i>Ballroom I</i> CP26 Mathematical Biology II • <i>Ballroom II</i> CP27 Coupled Oscillators II • <i>Ballroom III</i> CP28 Patterns II • Oscillators II • <i>Magpie A/B</i> CP29 Control II • <i>Wasatch A/B</i> CP30 Chaotic Maps II • <i>Golden Cliff</i> CP31 Solitons II • <i>Maybird</i> CP32 Numerics I • <i>Superior A</i> CP33 Transport II • <i>Superior B</i> CP34 PDEs II • <i>White Pine</i>	

# ations of Dynamical Systems 1999

**Wednesday**  
**May 26**

**7:30 AM-4:00 PM**  
Registration opens  
*Ballroom Lobby*

**8:30 AM-9:30 AM**  
IP7 Application of Dynamical Systems  
Theory to Spacecraft Trajectory  
Design Including GENESIS

*Kathleen C. Howell*  
*Ballrooms I, II, and III*

**9:30 AM-10:00 AM**  
Coffee  
*Ballroom Lobby*



**10:00 AM-12:00 PM**  
MS36 Topological Entropy and Average  
Expansion Rates • *Ballroom I*

MS37 Geometric Approximation Methods  
in Ocean Modeling • *Ballroom II*

MS38 Analysis and Application of Piecewise  
Smooth Dynamical Systems and Their  
Bifurcations • *Ballroom III*

MS39 Dynamics and Structures with  
Fractal Spectra • *Magpie A/B*

MS40 Space Missions and Dynamical  
Systems • *Wasatch A/B*

MS41 Dynamics of Scheduling Problems •  
*Golden Cliff*

MS42 Continuous Spectrum & Its Implications  
for Pattern Formation • *Maybird*

MS43 Calcium Dynamics: Oscillations,  
Sparks, & Waves • *Superior A*

MS44 Stochastic Stability of Dynamical  
Systems • *Superior B*

MS45 Geometric Analysis in Hydrodynamics •  
*White Pine*

**12:00 PM-1:30 PM**



Lunch  
Attendees are on their own.

**1:30 PM-2:30 PM**  
IP8 Quantitative Studies of the Fertilization  
Wave in Eggs

*Joel Keizer*  
*Ballrooms I, II, and III*

**2:30 PM-3:00 PM**



Coffee  
*Ballroom Lobby*

**3:00 PM-5:00 PM**

CP35 Data Analysis III • *Ballroom I*

CP36 Synchronization • *Ballroom II*

CP37 Pattern Formation in the Cahn-Hilliard  
Model-Part II • *Ballroom III*

CP38 Nonlinear Waves • *Magpie A/B*

CP39 Applications II • *Wasatch A/B*

CP40 Applications III • *Golden Cliff*

CP41 Forced Biosystems • *Maybird*

CP42 Patterns III • *Superior A*

CP43 Vortex Dynamics • *Superior B*

CP44 Polymers • *White Pine*

**5:00 PM-7:00 PM**



Dinner  
Attendees are on their own.

**7:00 PM-8:00 PM**

Poster presenters begin setting up their displays.  
Set-up to be completed by 8:00 PM.

**3:00 PM-10:00 PM**  
Poster Session and  
Dessert Reception



**10:00 PM**  
Posters are removed from the boards.

**Thursday**  
**May 27**

**7:30 AM-10:00 AM**  
Registration opens  
*Ballroom Lobby*

**8:30 AM-9:30 AM**  
IP9 DNA Evolution and Computation  
*Albert J. Libchaber*  
*Ballrooms I, II, and III*

**9:30 AM-10:00 AM**  
Coffee  
*Ballroom Lobby*



**10:00 AM-12:00 PM**  
MS46 Modeling of Chaotic Systems • *Ballroom I*

MS47 Complex Synchronization in  
Neuroscience • *Ballroom II*

MS48 Chaotic Advection in Temporally  
Chaotic Flows • *Ballroom III*

MS49 Applied Dynamics and Invariant  
Manifolds • *Magpie A/B*

MS50 Invariant Manifolds in Oscillation  
Problems • *Wasatch A/B*

MS51 Nonlinear Dynamics in Frontal  
Polymerization • *Golden Cliff*

MS52 Set-Oriented Methods in Study of  
Dynamical Systems • *Maybird*

MS53 Dynamics of Tethered Satellite Systems •  
*Superior A*

MS54 Bifurcation and Euclidean Symmetry •  
*Superior B*

MS55 Dynamics and Nonlinear ODEs in  
Industrial Applications • *White Pine*

**12:15 PM-1:15 PM**

IP10 Stability and Instability in  
Hamiltonian Dynamics

*Zhihong Jeff Xia*  
*Ballrooms I, II, and III*

**1:15 PM**

Conference adjourns

## Key to Abbreviations and Symbols

CP = Contributed Presentations

IP = Invited Plenary Presentations

MS = Minisymposium

= Coffee Breaks

= Lunch and Dinner Breaks

= Poster Session

## Audio-Visual Requirements

Two standard overhead projectors and two screens will be provided in the plenary session room. One overhead projector and one screen will be provided in each of the parallel session rooms. Speakers with special audiovisual equipment needs must inform SIAM of their specific requirements by Wednesday, April 21, 1999. If we do not hear from speakers by that date, it is understood that standard overhead projectors are all that is needed. Wednesday, April 21, 1999 is a firm deadline. Last minute requests cannot be honored. If a speaker sends a request for a special audiovisual equipment and decides not to use the requested equipment after it has been installed, or does not show up to give her/his presentation, the speaker is responsible for paying the rental fee. Some examples of special audiovisual equipment and rental fees are:

LCD Panel .....	\$300
35mm Slide Projector .....	\$50
Video Projector .....	\$550
1/2" VHS VCR .....	\$65
26" Data Monitor .....	\$300
Shure Mixer .....	\$25
Xenon 35mm Projector .....	\$200
Data Projector .....	\$600

For papers with multiple authors, the speaker is shown in *italics*, if known at press time.

## Time Allotted for Each Type of Presentation

- Contributed Presentations (CP) are 15 minutes plus 5 minutes for audience questions
- Invited Plenary Presentations (IP) are 50 minutes plus 5 minutes for audience questions
- Minisymposium Presentations (MS) are 25 minutes plus 5 minutes for audience questions
- Poster Sessions are 120 minutes

## Important Notice to Poster Presenters

Poster presenters are asked to set up their poster materials at 7:00 PM on Wednesday, May 26 in Ballrooms I, II and III. All poster materials must be up on the poster boards by 8:00PM. The poster session and dessert reception will officially open at 8:00 PM. All poster displays must be removed immediately at the end of the session at 10:00 PM. SIAM is not responsible for any materials left on the boards and discarded after 10:00 PM on Wednesday, May 26.

## Box Lunch Information

For those attendees who have purchased box lunches in advance, your lunch tickets are in your pre-registration packet. Those who want to purchase box lunches on-site, each lunch costs \$12.00 per day. Buy your lunch tickets at the SIAM registration desk. Box lunches are available Sunday, Monday, Tuesday and Wednesday.

## Invited Presentations

**Sunday, May 23**

8:30 AM-9:30 AM

**IP1 • Diffraction of Atoms by Real, Complex and Imaginary Crystals of Light**  
Sir Michael Berry, *H. H. Wills Physics Laboratory, University of Bristol, United Kingdom*

**Sunday, May 23**

1:30 PM-2:30 PM

**IP2 • Analysis of a Class of Strange Attractors**

Lai-Sang Young, *Department of Mathematics, University of California, Los Angeles; and Courant Institute of Mathematical Sciences, New York University*

**Monday, May 24**

8:30 AM-9:30 AM

**IP3 • Dynamics of Microstructure/Flow Interactions**

M. Gregory Forest, *Department of Mathematics, University of North Carolina, Chapel Hill*

**Monday, May 24**

1:30 PM-2:30 PM

**IP4 • Life at the Boundary of Chaos Theory and Nonequilibrium Statistical Mechanics**

J. Robert Dorfman, *Institute for Physical Science and Technology, University of Maryland, College Park*

**Tuesday, May 25**

8:30 AM-9:30 AM

**IP5 • Attractors in Evolutionary Equations**

Jack Hale, *School of Mathematics, Georgia Institute of Technology*

**Tuesday, May 25**

1:30 PM-2:30 PM

**IP6 • Finite Element Analysis of Nonsmooth Contact**

Michael Ortiz, *Graduate Aeronautical Laboratories, California Institute of Technology*

**Wednesday, May 26**

8:30 AM-9:30 AM

**IP7 • Application of Dynamical Systems Theory to Spacecraft Trajectory Design Including GENESIS**

Kathleen C. Howell, *Department of Aeronautics and Astronautics, Purdue University, West Lafayette*

**Wednesday, May 26**

1:30 PM-2:30 PM

**IP8 • Quantitative Studies of the Fertilization Wave in Eggs**

Joel Keizer, *Institute of Theoretical Dynamics, University of California, Davis*

**Thursday, May 27**

8:30 AM-9:30 AM

**IP9 • DNA Evolution and Computation**

Albert J. Libchaber, *Center for Studies in Physics and Biology, Rockefeller University*

**Thursday, May 27**

12:15 PM-1:15 PM

**IP10 • Stability and Instability in Hamiltonian Dynamics**

Zhihong Jeff Xia, *Department of Mathematics, Northwestern University*

All invited plenary presentations will take place in Ballrooms I, II, and III.

## General Information

### 1999 SIAM Conference on Dynamical Systems

#### Registration Fees

SIAG/DS Member*	\$195
SIAM Member	\$210
Non-Member	\$270
Student (after May 14, 1999)	\$45
* SIAM Activity Group on Dynamical Systems	

#### Forms of Payment

SIAM accepts American Express, MasterCard, Visa or checks as a form of payment.

#### Registration Fee Includes

- Welcoming Reception
- Coffee and Refreshments
- Poster Session and Dessert Reception
- Admission to all Technical Sessions
- Final Program and Abstract Booklet

#### Cancellation Fee

Before May 3, 1999 = Full Refund

May 4-14, 1999 = \$50.00 Cancellation Fee

After May 14, 1999 = No Refund

#### Registration Hours

The SIAM registration desk will be located in the Cliff Lodge Ballroom Lobby. It is open during the following times:

Saturday, May 22	6:00 PM-7:30 PM
Sunday, May 23	7:30 AM-4:00 PM
Monday, May 24	7:30 AM-4:00 PM
Tuesday, May 25	7:30 AM-4:00 PM
Wednesday, May 26	7:30 AM-4:00 PM
Thursday, May 27	7:30 AM-10:00 AM

#### Box Lunches

Box lunches are available Sunday through Wednesday. Each lunch costs \$12. There will be no prorated fees. No refunds will be issued after Friday, May 14, 1999. If your preregistration payment arrives at SIAM after the conference has started, that payment will be returned to you and your on-site registration will be processed.

#### E-mail

SIAM cannot offer e-mail access for individual attendees. We suggest you bring your own laptop computer and use hotel facilities. If you do not have your own personal laptop computer, the hotel business office offers this service at a nominal fee.

#### SIAM Membership

Non-SIAM members are encouraged to join SIAM to obtain the member rate for conference registration and enjoy the additional benefits of SIAM membership. As a member, you will receive free subscriptions to *SIAM Review* and *SIAM News*, and substantial discounts on SIAM books and journal subscriptions. Join SIAM by contacting Customer Service for an application form at:

**On-line:** [http://www.siam.org/  
about/memapp99.htm](http://www.siam.org/about/memapp99.htm)  
**Telephone:** 1-800-447-7426 (USA & Canada)  
+1-215-382-9800 (other countries)  
**Fax:** 1-215-386-7999  
**E-mail:** [service@siam.org](mailto:service@siam.org)  
**Mail:** SIAM  
3600 University City Science Center  
Philadelphia, PA 19104-2688 USA

#### SIAM Corporate Members

Non-member attendees who are employed by the following organizations are entitled to the SIAM member rate:

- Aerospace Corporation
- AT&T Laboratories—Research
- Bell Laboratories, Lucent Technologies
- Bellcore
- The Boeing Company
- E. I. DuPont de Nemours & Company
- Eastman Kodak Company
- Exxon Research and Engineering Company
- General Motors Corporation
- IBM Corporation
- ICASE
- IDA Center for Communications Research, La Jolla
- IDA Center for Communications Research, Princeton
- Institute for Defense Analyses, Center for Computing Sciences
- MacNeal-Schwendler Corporation
- Mathematical Sciences Research Institute
- Microsoft Corporation
- National Security Agency
- NEC Research Institute
- Oak Ridge National Laboratory, managed by the Lockheed Martin Energy Research Corporation for the Department of Energy
- Pacific Northwest National Laboratory, operated by Battelle
- Schlumberger-Doll Research
- Silicon Graphics, Inc.

#### Conference Tabletop Exhibitors

- Baltzer Science Publishers
- John Wiley & Sons
- Springer-Verlag
- VSP International Publishers

#### Hotel Facilities

The Cliff Lodge is a full-service modern hotel with roof-top outdoor heated swimming pool, three whirlpool hot tubs, and health spa. The Cliff Spa occupies the 9<sup>th</sup> and 10<sup>th</sup> floors of the Cliff Lodge and offers numerous services: massages, sauna, aerobics, and weight room. Spa facilities are available to SIAM attendees 18 years of age and older for a charge of \$10 per day. Guests staying longer than three days can purchase a \$30 pass valid for your entire stay. A wide variety of shops and boutiques are also available in the Snowbird Center and the Cliff Lodge. There are three tennis courts at Snowbird. For those who enjoy hiking and trekking, maps of the Snowbird area are available at the Activities Center. Mountain bicycles are available for rent.

#### Restaurants and Lounges

The Mexican Keyhole serves traditional Mexican entrees and drinks. Elegant dining can be found in the Aerie, a glass-enclosed rooftop restaurant with views of the mountains on all sides. Snowbird Village is the home of eight additional restaurants and lounges.

#### Parking at the Conference

There is complimentary valet parking available at the Cliff Lodge.

#### Telephone Messages

The telephone number of the Snowbird Resort and Conference Center is 1-800-453-3000 (US only) for reservations and 1-801-742-2222 to reach attendees. The hotel will either connect you with the SIAM registration desk or forward a message to the attendee's room.

#### Transportation Assistance

If you need assistance when booking your flight home, or in case of emergency, call 1-800-787-4315. Uniglobe Travel has 24 hour assistance available for all of its clients nationwide. If you need to take advantage of this free service, call 1-800-878-4315.

#### Ground Transportation from and to the Airport

Canyon Transportation, Inc. is a shuttle service that transports people between the airport and Snowbird. You must make a reservation for the shuttle in advance. Do this by calling Canyon Transportation at 1-800-255-1841, or by making a reservations with Snowbird's Central Reservations office. Remember to make a reservation for your departure from the conference. Canyon Transportation requires that you make a shuttle reservation 24 hours prior to your flight's scheduled departure.

# PROGRAM

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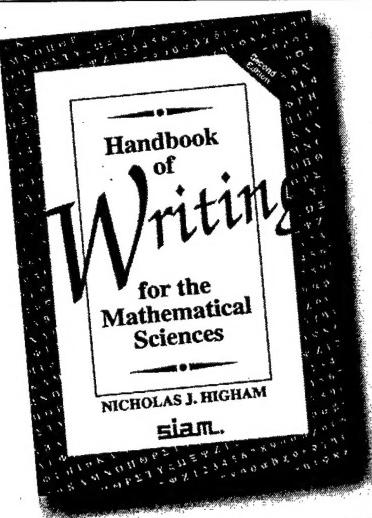
*Fifth SIAM Conference on*

**APPLICATIONS  
OF DYNAMICAL  
SYSTEMS**

**May 23-27, 1999**

**Snowbird Ski and Summer Resort • Snowbird, Utah**

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# Handbook of *Writing* for the Mathematical Sciences

## Nicholas J. Higham

The subject of mathematical writing is infused with life once again by Nick Higham. He follows up his successful HWMS volume with this much-anticipated second edition. As is Higham's style, the material is enlivened by anecdotes, unusual paper titles, and humorous quotations. This handy new volume provides even more information on the issues you will face when writing a technical paper or talk, from choosing the right journal in which to publish to handling your references. Its overview of the entire publication process is invaluable for anyone hoping to publish in a technical journal.

The original book has been completely revised, making use of feedback from readers as well as Higham's own large file of ideas, based on his experiences in reading, writing, editing, examining, and supervising theses.

The most obvious changes to this second edition are the new chapters: "Writing and Defending a Thesis," "Giving a Talk" (which adds to the existing material on preparing slides for a talk), "Preparing a Poster," and " $\text{\TeX}$  and  $\text{\LaTeX}$ " (including tips on their use for typesetting mathematics and detailed discussions of Bib $\text{\TeX}$  and indexing). Numerous mathematical symbols in the AMS fonts have been added to Appendix B.

Among the new material in existing chapters, the section "How to Referee" in the chapter, "Publishing a Paper," offers advice on this important aspect of the publication process. The chapter, "Writing a Paper," suggests formats for referencing items on the World Wide Web.

The renamed chapter, "Aids and Resources for Writing and Research," contains a new section, "Library Classification Schemes," which will help readers find their way around libraries. This chapter's material on the Internet was completely rewritten in light of the World Wide Web.

Separate author and subject indexes are now provided, the bibliography has been updated to include many new editions of books, and more than 70 new references have been added.

A Web page has been created for the book at [www.siam.org/books/ot63](http://www.siam.org/books/ot63). It includes updates relating to material in the book; links to references in the bibliography that are available on the Web; links to other Web pages related to mathematical writing,  $\text{\LaTeX}$ , and Bib $\text{\TeX}$ ; links to Web pages giving examples of posters; and the bibliography for the book in Bib $\text{\TeX}$  form.

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**Saturday, May 22**

Saturday, May 22

**Registration Open**

6:00 PM-7:30 PM

Location: Ballroom Lobby

Saturday, May 22

**Welcoming Reception**

6:00 PM-8:00 PM

Room: Ballrooms I, II &amp; III

**Sunday, May 23**

For papers with multiple authors,  
*the speaker is shown in italics*,  
 if known at press time.

Sunday, May 23

**Registration Open**

7:30 AM-4:00 PM

Location: Ballroom Lobby

Sunday, May 23

**Welcoming Remarks**

8:15 AM-8:30 AM

Room: Ballrooms I, II &amp; III

Emily Stone, Chair, Department of Mathematics and Statistics, Utah State University; and Dieter Armbruster, Co-chair, Department of Mathematics, Arizona State University

Sunday, May 23

**IP1****Diffraction of Atoms by Real, Complex and Imaginary Crystals of Light**

8:30 AM-9:30 AM

Room: Ballrooms I, II &amp; III

Chair: Steven H. Strogatz, Cornell University

Quantum atoms interact with light through a spatially-varying sinusoidal potential. This diffracts the atoms into a series of Bragg beams (previously studied for the diffraction of light by ultrasound). For real (nondissipative) potentials, classical motion is integrable; nevertheless, the semiclassical limit for thick crystals is ergodic, and caustics give large "twinkling" fluctuations. The potential can be made arbitrarily complex by adjusting the detuning. If it is purely imaginary, diffraction reveals nonhermitian degeneracies of the Bloch waves, and the distribution of intensities is dominated by complex rays rather than caustics. For complex potentials proportional to  $\exp(iKx)$ , the intensities can be calculated exactly, giving lopsided diffraction—and a dramatic violation of Friedel's law of crystallography, even a fractal.

Sir Michael Berry

H. H. Wills Physics Laboratory  
University of Bristol, United Kingdom

Sunday, May 23

**Coffee**

9:30 AM-10:00 AM

Location: Ballroom Lobby


**10:00 AM-12:00 PM**  
**Concurrent Sessions**

Sunday, May 23

**MS1****Differential Delay Equations: Theory and Applications****10:00 AM-12:00 PM**

Room: Ballroom I

This minisymposium will focus on recent developments in the theory and applications of differential-delay equations. The speakers will describe applications from high-dimensional systems (neural networks, networks of lasers) and engineering applications such as cutting tool dynamics. They will discuss theoretical studies involving traveling waves and bifurcation and anticipate that the presentations will appeal to researchers with an interest in infinite dimensional dynamical systems and to those concerned with the applications.

Organizer: John Mallet-Paret  
Brown University**10:00-10:25 Regenerative Effect and Chatter: An Analytical Study**Yan Liang and N. Sri Namachchivaya,  
University of Illinois, Urbana-Champaign**10:30-10:55 Nonexpansive Periodic Operators in  $\ell_1(\mathbb{Z})$  and Super-high-frequency Solutions of a Discontinuous Differential-Delay Equation**Roger D. Nussbaum, Rutgers University;  
and Eugenii Shustin, Tel Aviv University,  
Israel**11:00-11:25 Dynamics of Time Delayed Ring Laser Systems**

Rajarshi Roy, Georgia Institute of Technology

**11:30-11:55 Delay and Traveling Waves in Reaction-Diffusion Equations**

Xingfu Zou, Georgia Institute of Technology

Sunday, May 23

## MS2

### Synchronous Chaos and Invariant Manifolds

10:00 AM-12:00 PM

*Room: Ballroom II*

The phenomenon of synchronization of chaotic systems is interesting both because of potential applications and as a model for complex, but coherent motion in spatially extended systems, for example, biological systems. Recent work has now linked the phenomenon of synchronization to the more general one of motion on an invariant manifold. This symposium covers very recent results: (1) the use of k-hyperbolic manifolds to generate conditions for synchronization, (2) the possibility of failure of numerical shadowing of synchronous trajectories in some systems, (3) two attractor communication and (4) formulation of sufficient conditions for robust synchronization in real systems.

**Organizer:** Louis M. Pecora  
U.S. Naval Research Laboratory

#### 10:00-10:25 Invariant Manifolds and Chaotic Synchronization

Kresimir Josic, Pennsylvania State University and Boston University

#### 10:30-10:55 Unstable Dimension Variability and Modeling of Coupled Chaotic Oscillators

Ying-Cheng Lai, University of Kansas, Lawrence; and Celso Grebogi, University of Maryland, College Park

#### 11:00-11:25 Using Two-Attractor Chaotic Systems for Communication

Tom Carroll, U.S. Naval Research Laboratory and Louis M. Pecora, Organizer

#### 11:30-11:55 Experimental Evaluation of Several Proposed Criteria for Synchronization

Jonathan Blakely and Daniel Gauthier, Duke University

Sunday, May 23

## MS3

### Coping with Nonstationarity in Time Series Data from Nonlinear

10:00 AM-12:00 PM

*Room: Ballroom III*

Nonstationarity is one of the most relevant open problems in time series analysis. For many systems, nonstationarity is an intrinsic feature representing the time variation of the system's dynamics. The latter point of view leads to powerful new concepts to detect, analyze and cope with nonstationarity. Some of them, such as cross-prediction errors and recurrence plots, rely on deterministic structure underlying the data. Instead of segmenting data sets into almost stationary phases, the implicit reconstruction of the values of drifting parameters can restore stationarity requirements for applications such as noise reduction and signal classification. Nonlinear time series analysis has become a relevant tool for inverse problem. A new approach towards the problem of nonstationarity is of high relevance to broader applications of these methods, e.g. in the treatment of medical data, speech processing, and failure prediction in technical devices. In this minisymposium, the speakers will present relevant recent progress in this area which could stimulate a new philosophy, and consider certain types of nonstationarity as part of the (potentially nondeterministic) dynamics and treat the series as an entity.

**Organizers:** Holger Kantz  
Max-Planck Institut für Physik Komplexer Systeme, Dresden, Germany

Thomas Schreiber  
Universität Wuppertal, Germany

#### 10:00-10:25 Testing Stationarity in Time Series

Annette Witt, Jürgen Kurths, and Arkadi Pikovsky, Universität Potsdam, Germany

#### 10:30-10:55 Recurrence Plots Revisited

Martin Casdagli, Prediction Company, Santa Fe, New Mexico

#### 11:00-11:25 Clusters as a Basis for the Study of Non-Stationary Time Series

Thomas Schreiber, Organizer

#### 11:30-11:55 Coping with Nonstationarity by Over-Embedding

Holger Kantz, Organizer; Rainer Hegger, Max-Planck Institut für Physik Komplexer Systeme, Dresden, Germany; and Thomas Schreiber, Organizer

Sunday, May 23

## MS4

### Vortex Dynamics and Statistical Mechanics on Spheres

10:00 AM-12:00 PM

*Room: Magpie A/B*

This minisymposium will focus on recent developments in vortex dynamics and statistical mechanics on spherical surfaces. The work is motivated by applications in geophysical fluid dynamics where coherent structures, such as atmospheric cyclones or oceanographic eddies, persist over long times and travel over such large distances, that the spherical geometry of the earth becomes important. The systems are modeled by the Euler equations from two-dimensional fluid mechanics, hence Hamiltonian techniques are widely used. For most applications, viscous effects can be ignored, although effects of rotation are also generally considered important. The speakers in this minisymposium will provide a snapshot of current activity in this area.

**Organizers:** Paul K. Newton  
University of Southern California

Chjan C. Lim  
Rensselaer Polytechnic Institute

#### 10:00-10:25 Integrable Vortex Dynamics on a Sphere

Paul K. Newton, Organizer

#### 10:30-10:55 Equilibrium Statistics and Dynamics of Point Vortices on a Rotating Sphere

Chjan C. Lim, Organizer

#### 11:00-11:25 Discrete Euler-Poincaré and Lie-Poisson Equations

Sergey Pekarsky and Jerrold Marsden, California Institute of Technology

#### 11:30-11:55 Finite Symmetry Methods for N Identical Vortices on the Sphere

James Montaldi, Institut Non-Linéaire de Nice, Valbonne, France

Sunday, May 23

## MS5

### Applications of Nonlinear Dynamics to Problems from Industry and Nature

10:00 AM-12:00 PM

Room: Wasatch A/B

This minisymposium will focus on applications of nonlinear dynamics to industrial problems. Although the speakers will discuss a broad range of work, all of the talks satisfy three criteria: (1) the problem originated from outside the nonlinear dynamics community, (2) the methods used to successfully solve the problem come from the nonlinear dynamics community, and (3) the criteria used to measure success come from the community that originated the problem. The last criterion is important because the originator of a problem often gauges success using criteria that are different from those used by the nonlinear dynamics community.

**Organizer:** Reggie Brown  
College of William and Mary

**10:00-10:25 Generating Random Numbers Via Deterministic Chaos**  
*Ljupco Kocarev and Toni Stojanovski, College of William and Mary*

**10:30-10:55 Constructing Transportable Behavioral Models of Nonlinear Electronic Devices**

*David M. Walker, Hewlett Packard Laboratories, and College of William and Mary; Reggie Brown, Organizer; and Nicholas B. Tufillaro, College of William and Mary, and Hewlett Packard Laboratories*

**11:00-11:25 Chaotic Dynamics and Modeling of Power System Loads**  
*Eric Kostelich, Gerald Heydt, and Efrain O'Neill, Arizona State University*

**11:30-11:55 Cargo Transfer with Shipboard Cranes: Control, Prediction and Simulation**  
*Brian R. Hunt, University of Maryland, College Park*

Sunday, May 23

## MS6

### Ergodic Theory of Hyperbolic Dynamical Systems

10:00 AM-12:00 PM

Room: Golden Cliff

The ergodic theory of hyperbolic dynamical systems has been fundamental to the understanding of "chaotic" systems and to the development of a rigorous foundation for statistical mechanics. This minisymposium will address recent results for systems that are not uniformly hyperbolic and in particular results on stable ergodicity which have led to the provision of a large class of models that retain strong mixing properties under deterministic perturbation. These models arise naturally in applications with Lie group symmetry.

**Organizer:** Matthew J. Nicol  
UMIST, Manchester, United Kingdom

**10:00-10:25 Ergodic Theory of Equivariant Diffeomorphisms**

*Michael Field, University of Houston*

**10:30-10:55 Lyapunov Exponents and Partially-Hyperbolic Systems**

*Amie Wilkinson, Northwestern University*

**11:00-11:25 Ergodic Properties of a Class of Skew Products**

*Charles Walkden, University of Manchester, United Kingdom*

**11:30-11:55 The Dynamics of a Class of Nonuniformly Hyperbolic Attractor of Solenoid Type**

*Don Wang, University of California, Los Angeles*

Sunday, May 23

## MS7

### Dynamics of the Complex Ginzburg-Landau Equation: Experiment and Theory

10:00 AM-12:00 PM

Room: Maybird

The Complex Ginzburg-Landau (CGL) equation and its variants describe a wide variety of physical phenomena. The rich dynamics coupled with the relative simplicity of the equations create a fertile landscape for studying the dynamics of nonlinear PDEs and the physical systems they describe in this minisymposium. Experimentalists (R. Ecke, M. Dennin) will discuss the determination of CGL coefficients and evidence for periodic and chaotic behavior in two fluid systems. Theorists (H. Riecke, D. Egolf) will describe behavioral transitions, the role of topological defects, and Langevin equation descriptions of long-wavelength behavior in spatiotemporally chaotic CGL equations.

**Organizer:** David A. Egolf  
Los Alamos National Laboratory

**10:00-10:25 Transition from Ordered to Disordered Defect Chaos**

*Hermann Riecke, Northwestern University; and Glen D. Granzow, Idaho State University*

**10:30-10:55 Spatiotemporal Chaos in Electroconvection: An Application of Coupled CGL Equations**

*Michael Dennin, University of California, Irvine*

**11:00-11:25 The Complex Ginzburg-Landau Equation: Connection to Physical Experiment**

*Robert E. Ecke, Los Alamos National Laboratory*

**11:30-11:55 Long Wavelength Behavior In the 1D Complex Ginzburg-Landau Equation**

*David A. Egolf, Organizer*

Sunday, May 23

## MS8

### Fourth-Order Hamiltonian Systems and Variational Techniques in Dynamics

10:00 AM-11:30 AM

*Room: Superior A*

Fourth-order Hamiltonian systems arise in many physical models from areas such as phase transitions, optics, and nonlinear elasticity. These systems can be studied using variational methods or techniques from the theory of dynamical systems. In many cases, a combination of ideas from both areas has provided the most successful analysis. The speakers in this minisymposium will discuss these approaches and explore applications and related problems, such as pattern formation in evolution equations and elliptic systems.

**Organizers:** William Kalies  
Florida Atlantic University

Robert VanderVorst  
Georgia Institute of Technology

#### 10:00-10:25 Snaking Curves of Multibumps, Degenerate Hamiltonian Hopf Bifurcation and Cellular Buckling of Long Structures

Alan Champneys and Patrick D. Woods,  
University of Bristol, United Kingdom

#### 10:30-10:55 The Saddle-Focus Induced Homotopy Classes and Their Action Minimizing Orbits for Hamiltonian Systems with Two Degrees of Freedom

Jaroslaw Kwapisz, Montana State University

#### 11:00-11:25 An Elliptic Equation with Spike Solutions Concentrating at Local Minima of the Laplacian

Gregory S. Spradlin, United States Military Academy

Sunday, May 23

## MS9

### Lattice Dynamical Systems: Theory and Applications

10:00 AM-12:00 PM

*Room: Superior B*

Lattice Dynamical Systems (LDS) emerged since mid-eighties as a new tool to study space-time dynamics. LDS also serve as an extremely useful tool for numerical modeling of spatially extended dynamical systems. More recently LDS were successfully used for a control of chaos in extended systems and for the studies of selforganization in spatially discrete systems. The speakers will discuss thermodynamics of LDS, control of extended dynamical systems, and order-chaos transitions and collective behavior in LDS.

**Organizer:** Leonid A. Bunimovich  
Georgia Institute of Technology

#### 10:00-10:25 Bifurcations of Localized Structures in Lattice Systems

Leonid A. Bunimovich, Organizer

#### 10:30-10:55 Collective Behavior of Lattices of Strongly-Coupled Chaotic Maps

Hugues Chaté and Anaël Lemaître, Centre d'Etudes de Saclay, France

#### 11:00-11:25 Symmetry and Control of Extended Dynamical Systems

Roman O. Grigoriev, University of Chicago

#### 11:30-11:55 Existence, Uniqueness, and Smooth Dependence of Thermodynamic Limits of SRB Measures

Miaohua Jiang, Wake Forest University

Sunday, May 23

## MS10

### Nonlinear Dynamics of Solids, Shells, and Rods

10:00 AM-12:30 PM

*Room: White Pine*

The speakers in this minisymposium will address theoretical and computational aspects of nonlinear dynamics of solids especially structures such as shells and rods used by engineers. Energy-momentum and dissipative integration schemes, reduction methods, existence of inertial manifolds, chaotic and regular motion in shells are some aspects of the minisymposium: (1) Since the stability property of time integration schemes become very important when dealing with very large systems, robust integration schemes have to be constructed. Efforts recently taken in developing mechanical integrators that preserve the essential features of the mechanical system, e.g., the momentum, the energy, or the symplectic structure, will be focused on. (2) Several ideas of extending some techniques and applications of reduction methods that were originally developed in the context of Fluid Mechanics, to the context of the Theory of Elasticity and Solid Structures will be given. Applications to mechanical structures of the POD method, the nonlinear Galerkin or the post processed Galerkin method to approximate Inertial Manifolds, will be discussed. (3) Bifurcations, chaotic and free large over-all motion of such structures are of interest and will be taken as examples.

**Organizers:** Peter Wriggers  
Darmstadt University of Technology, Germany

Carlo Sansour  
University of Karlsruhe, Germany

#### 10:00-10:25 Postprocessing Galerkin Methods

Edriss Titi, University of California, Irvine

#### 10:30-10:55 Nonlinear Oscillations of a Fluid Conveying Tube with an End Mass

Alois Steindl, Hans Troger, and Bernhard Albrecht, Vienna University of Technology, Austria

#### 11:00-11:25 Time-Stepping Algorithms with Controllable High-Frequency Dissipation for Nonlinear Dynamics

Francisco Armero and Ignacio Romero, University of California, Berkeley

**11:30-11:55 The Post-Processed Galerkin Method Applied to Nonlinear Shell Vibrations**

*Carlo R. Laing*, University of Pittsburgh; and Allan McRobie, Cambridge University, United Kingdom

**12:00-12:25 Geometric Exact Models, Energy-Momentum Methods, and Active Degrees of Freedom for the Dynamics of Shells and Rods**

*Carlo Sansour* and Peter Wriggers, Organizers; and Jamal Sansour, University of Hannover, Germany

Sunday, May 23

**Lunch**

12:00 PM-1:30 PM



Attendees are on their own.

Sunday, May 23

**IP2****Analysis of a Class of Strange Attractors**

1:30 PM-2:30 PM

*Room: Ballrooms I, II & III**Chair: Konstantin Mischaikow, Georgia Institute of Technology*

The speaker will introduce a new class of attractors and present a multi-faceted analysis of their dynamical properties. This class includes as special cases some familiar objects such as the Axiom A solenoid, Hénon attractors and dissipative twist maps. The speaker will discuss results on the chaotic behavior, global geometry, symbolic representation, topological complexity and statistical properties of these attractors.

**Lai-Sang Young**

*Department of Mathematics University of California, Los Angeles; and Courant Institute of Mathematical Sciences, New York University*

Sunday, May 23

**Coffee**

2:30 PM-3:00 PM

*Location: Ballroom Lobby*


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**3:00 PM-5:00 PM Concurrent Sessions**

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Sunday, May 23

**CP1****Neurons**

3:00 PM-5:00 PM

*Room: Ballroom I**Chair: Robert M. Miura, University of British Columbia, Vancouver, Canada***3:00-3:15 Rate-Dependent Activity in Excitable Cells**

Jennifer S. Enns-Ruttan and *Robert M. Miura*, University of British Columbia, Vancouver, Canada

**3:20-3:35 Understanding Interspike Interval Variability**

*Tay Netoff*, George Mason University and George Washington University; Paul So, Bruce Gluckman, Joseph T. Francis, and Steven J. Schiff, George Mason University

**3:40-3:55 Dimension Estimation for Seizure Prediction and Localization**

Kristin Jerger, George Washington University Medical Center and George Mason University

**4:00-4:15 Synchronous Behavior of Two Coupled Biological Neurons**

Robert C. Elson, University of California, San Diego; Allen I. Selverston, Instituto de Neurobiología, Old San Juan, Puerto Rico; Ramón Huerta, Universidad Autónoma de Madrid, España; *Nikolai F. Rulkov*, Mikhail I. Rabinovich, and Henry D. I. Abarbanel, University of California, San Diego

**4:20-4:35 Genesis of Coherent Structures in a Discrete Chaotic Neural Medium**

Mikhail I. Rabinovich, *Joaquín J. Torres*, Pablo Varona and Ramón Huerta, University of California, San Diego; and Patrick Weidman, University of Colorado, Boulder

**4:40-4:55 A Study of Oscillatory Activity in the Model of the Septo-Hippocampal System**

*Roman Borisyuk* and Michael Denham, University of Plymouth, United Kingdom

Sunday, May 23

## CP2

### Fluids

**3:00 PM-5:00 PM**

*Room: Ballroom II*

*Chair: Charles R. Doering, University of Michigan, Ann Arbor*

**3:00-3:15 Laminar and Turbulent Energy Dissipation In a Shear Boundary Layer with Suction**

*Charles R. Doering and Rodney A. Worthing, University of Michigan, Ann Arbor; and Edward A. Spiegel, Columbia University*

**3:20-3:35 Time-Dependent Flow Regimes in Two-Phase Flows and Compressible Fluids**

*Jayati Johri and Benjamin J. Glasser, Rutgers, The State University of New Jersey*

**3:40-3:55 Spatial and Temporal Resonances in a Periodically Forced Extended System**

*J. M. Lopez, Arizona State University; and F. Marques, Universitat Politecnica de Catalunya, Barcelona, España*

**4:00-4:15 Asymptotic Regime of the Rayleigh-Taylor Instability in the Large-Time Limit**

*Toshio Yoshikawa and Alexander M. Balk, University of Utah*

**4:20-4:35 Connecting Double Points in Rayleigh-Bénard Convection**

*John H. Bolstad, Lawrence Livermore National Laboratory*

**4:40-4:55 Stability Analysis of Perturbed Plane Couette Flow**

*Laurette Tuckerman, LIMSI-CNRS, Orsay, France; and Dwight Barkley, University of Warwick, United Kingdom*

Sunday, May 23

## CP3

### Communication

**3:00 PM-5:00 PM**

*Room: Ballroom III*

*Chair: Ned J. Corron, Dynetics, Inc., Huntsville, Alabama*

**3:00-3:15 Chaos Communications Using Virtual Synchronization**

*Ned J. Corron, Dynetics, Inc., Huntsville, Alabama*

**3:20-3:35 Security Issues in Chaotic Communications**

*Andrew T. Parker and Kevin M. Short, University of New Hampshire*

**3:40-3:55 Multiple-Scale Averaging and Optimization of Amplifier Placement in Multi-Channel Dispersion-Managed Soliton Transmission**

*Brian Marks, William L. Kath, and Tian-Shiang Yang, Northwestern University; and Sergei K. Turitsyn, Aston University, Birmingham, United Kingdom*

**4:00-4:15 Theory of Wavelength Division Multiplexing in Fiber Links with Dispersion Management**

*Ildar Gabitov, Los Alamos National Laboratory*

**4:20-4:35 Polarization-Based Laser Communication Schemes**

*John B. Geddes and Kevin M. Short, University of New Hampshire*

**4:40-4:55 Premature Synchronisation in Coupled Maps**

*Giovanni Santoboni and Steven R. Bishop, University College London, United Kingdom; and Rua Murray, University of Victoria, Canada*

Sunday, May 23

## CP4

### Applications I: Geophysical and Industrial

**3:00 PM-4:40 PM**

*Room: Magpie A/B*

*Chair: Kay A. Robbins, University of Texas, San Antonio*

### Geophysical

**3:00-3:15 Symmetry-Breaking Bifurcations in a Hopf/Steady-State Mode Interaction in Three-Dimensional Magnetohydroconvection**

*Jonathan H. P. Dawes, University of Cambridge, United Kingdom*

**3:20-3:35 Double Hopf Bifurcation in a Geophysical Fluid Dynamics Model**

*Gregory M. Lewis and Wayne Nagata, University of British Columbia, Vancouver, Canada*

### Industrial

**3:40-3:55 Thermo-Acoustic Instabilities in Aeropropulsion Systems**

*D. Dane Quinn, The University of Akron*

**4:00-4:15 Singular Poincaré-Andronov-Hopf Bifurcation to Relaxation Oscillations During High-Speed Metal Cutting**

*Timothy J. Burns and Matthew A. Davies, National Institute of Standards and Technology, Gaithersburg*

**4:20-4:35 Visual Interpretation of Transitions in Spatiotemporal Systems**

*Kay A. Robbins, University of Texas, San Antonio*

Sunday, May 23

**CP5****Bifurcations with Symmetry****3:00 PM-5:00 PM***Room: Wasatch A/B**Chair: Martin Golubitsky, University of Houston***3:00-3:15 Chaotic Direction-Reversing Waves***Edgar Knobloch and Jeff Moehlis, University of California, Berkeley; and Adam S. Landsberg, Claremont McKenna, Scripps, and Pitzer Colleges***3:20-3:35 Bursts in Oscillatory Systems with Broken  $D_4$  Symmetry***Jeff Moehlis and Edgar Knobloch, University of California, Berkeley***3:40-3:55 A Model of Central Pattern Generators for Quadruped Locomotion***Pietro-Luciano Buono, University of Ottawa, Canada; Martin Golubitsky, University of Houston; Ian Stewart, University of Warwick, United Kingdom; and J. J. Collins, Boston University***4:00-4:15 Doubly Forced Oscillators***Bruce B. Peckham, University of Minnesota, Duluth; and Ioannis G. Kevrekidis, Princeton University***4:20-4:35 Heteroclinic Cycles In Networks of Cells with  $D_n$ - Symmetry***Pietro-Luciano Buono, University of Ottawa, Canada; Martin Golubitsky and Antonio Palacios, University of Houston***4:40-4:55 Normal Forms via Non-Normal Means***B. D. Coller and R. Chamara, University of Illinois, Chicago*

Sunday, May 23

**CP6****Nonlinear Optics****3:00 PM-5:00 PM***Room: Golden Cliff**Chair: William L. Kath, Northwestern University***3:00-3:15 Dynamics of Wavelength-Division-Multiplexed Transmission of Return-to-Zero Pulses In Dispersion-Managed Optical Fibers***Tian-Shiang Yang and William L. Kath, Northwestern University; and Stephen G. Evangelides Jr., Tyco Submarine Systems Ltd. Laboratories***3:20-3:35 Estimating Parameters in Laser Dynamics***Jens Timmer and Werner Horbelt, University of Freiburg, Germany; and Martin Bünner, Marco Ciofini, and Riccardo Meucci, Istituto Nazionale di Ottica, Florence, Italy***3:40-3:55 BI-Instability and Ultrasubharmonics In a Modulated Laser***Thomas W. Carr, Southern Methodist University; and Ira B. Schwartz, Naval Research Laboratory***4:00-4:15 Dynamics of Low-Amplitude Resonant Light-Matter Interaction***Julie A. Byrne, Rensselaer Polytechnic Institute***4:20-4:35 Controlling Resonant Wave Interactions to Enhance Frequency Conversion in Nonlinear Optics***Gregory G. Luther, Northwestern University***4:40-4:55 Self-Pulsations of a Lasers with Saturable Absorber***Johan L.A. Dubbeldam, Vrije Universiteit, The Netherlands; and Bernd Krauskopf, University of Bristol, United Kingdom*

Sunday, May 23

**CP7****Homoclinic Dynamics****3:00 PM-5:00 PM***Room: Maybird**Chair: Richard Haberman, Southern Methodist University***3:00-3:15 Slow Passage Through a Saddle-Center Bifurcation***Richard Haberman, Southern Methodist University***3:20-3:35 Homoclinic Bifurcations and Chaos in the Presence of a Center Manifold***Joseph Gruendler, North Carolina A&T State University***3:40-3:55 Homoclinic and Heteroclinic Orbits In Cylinder Buckling***Gabriel Lord, National Physical Laboratory, Teddington, United Kingdom; Alan Champneys, University of Bristol, United Kingdom; and Giles Hunt, University of Bath, United Kingdom***4:00-4:15 Homoclinic and Heteroclinic Orbits for Singularly Perturbed Nearly Integrable Systems***Shangbing Ai, University of Pittsburgh***4:20-4:35 Heteroclinic Bifurcations as the Onset of Voltage Collapse in a Power System Model***Hinke Osinga, California Institute of Technology***4:40-4:55 Homoclinic and Heteroclinic Motions for Resonant Periodic Orbits In Forced, Two-Degree-of-Freedom Systems***Kazuyuki Yagasaki, Gifu University, Japan*

Sunday, May 23

## CP8

### Materials

**3:00 PM-4:40 PM**

*Room: Superior A*

*Chair: Michael Grinfeld, University of Strathclyde, Glasgow, Scotland*

**3:00-3:15 An Integrodifferential Model of Phase Separation**

Dugald B. Duncan, Heriot-Watt University, Edinburgh, Scotland; *Michael Grinfeld* and Iulian Stoleriu, University of Strathclyde, Glasgow, Scotland

**3:20-3:35 Propagation of Phase Transformation Front in 1D Shape Memory Alloys Induced by Impact Loading**

Alexander Bekker, Texas A&M University, College Station

**3:40-3:55 Nucleation Dynamics of Cahn-Hilliard Equation**

Junping Shi, Tulane University

**4:00-4:15 Critical States and Minima for an Energy with Second Order Gradients**

F. Dias, CNRS and Université de Nice – Sophia Antipolis, France; and J. M. Ghidaglia, Ecole Normale Supérieure de Cachan and CNRS, Cachan Cedex, France

**4:20-4:35 Disjoining Potential and Spreading of Thin Liquid Layers in Diffuse Interface Model Coupled to Hydrodynamics**

*Len Pismen*, Northwestern University; and Yves Pomeau, Ecole Normale Supérieure, France

Sunday, May 23

## CP9

### Bifurcations in Nonsmooth Systems

**3:00 PM-4:00 PM**

*Room: Superior B*

*Chair: To be announced*

**3:00-3:15 Asymptotic Behavior in a Two Degree of Freedom Mechanical System with a Stop**

*Andre Xavier C. N. Valente*, and Igor Mezic, University of California, Santa Barbara; and Harris McClamroch, University of Michigan, Ann Arbor

**3:20-3:35 Dynamics and Control of a Constrained Impact Oscillator**

*Eugenio Gutierrez Tenreiro* and Jose M. Zaldivar, Commission of the European Communities, Ispra, Italy

**3:40-3:55 Intermittent Phase Transitions in a Two-Dimensional Stick-Slip Model of Earthquakes**

Vladimir B. Ryabov, Kobe University, Japan

Sunday, May 23

## Dinner

**5:00 PM-7:00 PM**

Attendees are on their own.



## Monday, May 24

For papers with multiple authors,  
the speaker is shown in *italics*,  
if known at press time.

Monday, May 24

## Registration Open

**7:30 AM-4:00 PM**

*Location: Ballroom Lobby*

Monday, May 24

## IP3

### Dynamics of Microstructure/ Flow Interactions

**8:30 AM-9:30 AM**

*Room: Ballrooms I, II & III*

*Chair: Raymond Goldstein, University of Arizona*

Many complex materials such as polymers and liquid crystal polymers are processed as “melts” in special geometries and flows, both for technological purposes (super-strength materials) and in natural biological functions (spiders spinning silk). Molecular-scale orientation interacts with the flow and any free surface effects, yielding remarkable phenomena which are difficult to explain. The speaker will describe constitutive laws for flows of rod-like molecules, and then apply the moment averaged equations of Doi and co-workers to probe two phenomena rich in dynamical systems flavor: microstructural suppression of the Rayleigh capillary instability, and the classical isotropic-to-nematic phase transition in the presence of an imposed flow.

**M. Gregory Forest**

*Department of Mathematics, University of North Carolina, Chapel Hill*

Monday, May 24

## Coffee

**9:30 AM-10:00 AM**

*Location: Ballroom Lobby*



**10:00 AM-12:00 PM**  
**Concurrent Sessions**

Monday, May 24

## **MS11**

### **Chaos and Communication**

**10:00 AM-12:00 PM**

*Room: Ballroom I*

The main issues to be addressed in this minisymposium are: optimal symbolic representation with judiciously chosen generating partitions, efficient message encoding, channel capacity, multiplexing, signal dropout reconstruction, and experimental results with erbium doped ring lasers in communication with chaotic optical systems. The basic common ground for all these issues is that chaotic signals can be controlled with very small perturbations which cause no significant change in the topological dynamics. Chaotic signals are naturally complex and provide a vehicle for information transmission that will often have technological advantages. Some of them will also be addressed in this minisymposium.

**Organizers:** Epaminondas Rosa, Jr.  
*University of Miami*

Celso Grebogi  
*University of Maryland, College Park*

**10:00-10:25 Communicating with Chaos**

Celso Grebogi, Organizer

**10:30-10:55 Communicating with Chaos Using Two-Dimensional Symbolic Dynamics**

Ying-Cheng Lai, University of Kansas

**11:00-11:25 Redundant Chaotic Signals**

Epaminondas Rosa, Jr., Organizer

**11:30-11:55 Communication with Chaotic Waveforms**

Rajarshi Roy, Georgia Institute of Technology

Monday, May 24

## **MS12**

### **Applied Topology in Dynamics**

**10:00 AM-12:00 PM**

*Room: Ballroom II*

Many ideas in dynamics are based on topology. This minisymposium will display a wide variety of interactions where the topology tells the scientist what behavior to expect. For example, the topology of Fermi surfaces determines the conductivity properties of "normal" metals in strong magnetic fields (Novikov). Similarly basic topological considerations determine the recurrence patterns in (non-convex) open billiards (Kennedy). The topological theory of Cartheodory, Cartwright, and Littlewood allows Alligood to describe sudden changes in the recurrent sets of the forced damped pendulum. For Barge the continuity of topology determines the discrete arrangements of tilings and quasicrystals.

**Organizers:** James A. Yorke and Serguei P. Novikov  
*University of Maryland, College Park*

**10:00-10:25 Topological Phenomena in the 3D Single Crystal Normal Metals**

Serguei P. Novikov, Organizer

**10:30-10:55 Topology of One-Dimensional Tilings**

Marcy Barge, Montana State University, Bozeman

**11:00-11:25 The Topology of Explosions: Sudden Appearance of Recurrent Points**

Kathleen T. Alligood, George Mason University

**11:30-11:55 Topological Horseshoes**

Judy Kennedy, University of Delaware; James A. Yorke, Organizer; and Sahin Kocak, Anadolu University, Turkey

Monday, May 24

## **MS13**

### **Dynamical Data Analysis in Biology**

**10:00 AM-12:00 PM**

*Room: Ballroom III*

The speakers in this minisymposium will discuss current applications of time series analysis and control techniques in biological settings. The applications include the control of a cardiac arrhythmia; a dynamical characterization of tremor; the dynamics of a network of neurons in the mammalian hippocampus; and identifying saddle periodic points in noisy experimental time series.

**Organizers:** Eric Kostelich  
*Arizona State University*

Timothy Sauer  
*George Mason University*

**10:00-10:25 Dynamic Control of Cardiac Alternans**

Kevin Hall and Leon Glass, McGill University, Canada; David Christini and James J. Collins, Boston University; and Jacques Billette, Université de Montréal, Canada

**10:30-10:55 Cross-Spectral Analysis of Tremor Time Series**

Jens Timmer, Michael Lauk and C. H. Lücking, Universität Freiburg, Germany; and G. Deuschl, Universität Kiel, Germany

**11:00-11:25 Using Control Blindly to Find Unstable Periodic Orbits**

Daniel T. Kaplan, Macalester College

**11:30-11:55 Shedding Light on Neuronal Dynamical "Dark Matter"**

Steven J. Schiff, Joseph T. Francis, Bruce J. Gluckman, and Paul T. So, George Mason University

Monday, May 24

## **MS14**

### **Characterization of Spatiotemporal Chaos**

**10:00 AM-12:30 PM**

*Room: Magpie A/B*

Despite the identification of spatiotemporal chaos (STC) in many physical systems, e.g. lasers, fibrillating hearts, convecting fluids, and flame fronts, a theoretical understanding of STC remains elusive. Characterization of the STC state is an essential first step towards the development of a theory. The speakers in this minisymposium will focus on four directions for characterizing STC, including the development of order parameters that distinguish chaotic states, reduced wavelet descriptions of spatiotemporal chaotic partial differential equations, unstable periodic orbit analysis of high-dimensional attractors, and the control and perturbation of spatially extended systems.

**Organizer:** Scott M. Zoldi  
*Los Alamos National Laboratory*

#### **10:00-10:25 Controlling Turbulence by Global Feedbacks**

Dorjsuren Battogtokh, Kyoto University, Japan; and Alexander S. Mikhailov, Fritz Haber Institute der MPG, Berlin, Germany

#### **10:30-10:55 Characterizations of Natural Patterns**

Gemunu H. Gunaratne, University of Houston

#### **11:00-11:25 A Wavelet-Based Investigation of a Spatiotemporally Chaotic System**

Ralf W. Wittenberg, University of Minnesota, Minneapolis; and Philip Holmes, Princeton University

#### **11:30-11:55 Periodic Orbit Analysis of High Dimensional Spatiotemporal Chaos**

Scott M. Zoldi, Organizer; and Henry S. Greenside, Duke University

#### **12:00-12:25 Characterization and Control of Spatiotemporal Systems**

Nita Parekh, Centre for Cellular and Molecular Biology, Hyderabad, India; V. Ravi Kumar and B. D. Kulkarni, National Chemical Laboratory, India

Monday, May 24

## **MS15**

### **Nonlinear Dynamics of Partial Differential Evolution Equations and Applications**

**10:00 AM-12:00 PM**

*Room: Wasatch A/B*

In the past decade, a great deal of progress was made in using dynamical systems and solitons to studying the dynamics of nonlinear partial differential equations. Many applications, such as nonlinear optics, furnish examples that exhibit both very regular and chaotic dynamics. There has, therefore, always existed a beneficial mutual interaction between these fields and various branches of dynamical systems, including, more recently, those pertaining to partial differential equations. The speakers in this minisymposium will illustrate this interaction by describing the dynamical behavior of specific partial differential equations that arise in nonlinear optics and other applied fields, and discussing several new techniques. These include dynamical systems analysis of homoclinic orbits and chaotic dynamics in partial differential equations, turbulence theory, kinetic equations, numerical computations and diagnostics for nonlinear partial differential equations, and perturbation theory for near-integrable partial differential equations and solitons. Applications will include semiconductor lasers, long ring-cavity gas lasers, and fiber optics. Analytical and numerical studies will be presented.

**Organizer:** Gregor Kovacic  
*Rensselaer Polytechnic Institute*

#### **10:00-10:25 Soliton Perturbations and the Random Kepler Problem**

Jared C. Bronski, University of Illinois, Urbana-Champaign; Fatkhulla Kh. Abdullaev, Physical-Technical Institute, Uzbekistan; and G. Papanicolaou, Stanford University

#### **10:30-10:55 Shilnikov Manifolds in Coupled Nonlinear Schrödinger Equations**

George Haller, Brown University

#### **11:00-11:25 Weak Turbulence with Applications to Semiconductor Lasers and Fiber Optics**

Yuri Lvov, Los Alamos National Laboratory

#### **11:30-11:55 Dynamics of Long Ring Lasers**

Gregor Kovacic, Organizer; and Ilya Timofeyev, Courant Institute of Mathematical Sciences, New York University

Monday, May 24

## **MS16**

### **Numerical Analysis of Contact Problems Involving Friction**

**10:00 AM-12:00 PM**

*Room: Golden Cliff*

The objective of this minisymposium is to present current developments in the area of robust contact algorithms capable of dealing with multibody contact problems. The bodies may be rigid or elastic and some of the systems may involve friction and fragmentation. The minisymposium will feature the formulation and analysis of the proposed methods, as well as their numerical implementation. Some of the presentations will provide numerical simulations that illustrate the performance of the techniques.

**Organizer:** Coura Kane  
*California Institute of Technology*

#### **10:00-10:25 Variational Structure/Numerics of Contact Problems**

Coura Kane, Organizer; Jerrold E. Marsden and Michael Ortiz, California Institute of Technology

#### **10:30-10:55 Numerical Analysis of Dynamic Contact/Impact In Elastic Multi-Body Systems**

Francisco Armero, University of California, Berkeley

#### **11:00-11:25 Symplectic-Energy-Momentum Integrators**

Jerrold E. Marsden, California Institute of Technology; Coura Kane, Organizer; and Michael Ortiz, California Institute of Technology

#### **11:30-11:55 Smooth Interpolations for Frictional Contact Problems**

Peter Wriggers and Louvre Krostulovic-Opara, Universität Hannover, Germany

Monday, May 24

**MS17****Analysis and Computation of Bistable Differential-Difference Equations**

10:00 AM-12:00 PM

Room: *Maybird*

We focus on recent developments in the analysis and computation of bistable differential-difference equations, including reaction-diffusion and Cahn-Hilliard like equations. The problem areas include integrodifferential models for both spatially discrete and spatially continuous systems, a Fredholm theory for equations with backward and forward delays to analyze the structure of traveling wave solutions and that forms the basis for a numerical technique for the computation of traveling waves, and analysis and computational techniques for equilibrium solutions of spatially discrete Cahn-Hilliard equations. An important issue to be addressed is the relative impact of both spatially discrete and continuous terms on the dynamics.

**Organizer:** Erik S. Van Vleck  
*Colorado School of Mines*

**10:00-10:25 A Discrete Convolution Model for Phase Transitions**

Peter Bates, Brigham Young University; and Adam Chmaj, Utah State University

**10:30-10:55 A Variant of Newton's Method for the Computation of Traveling Wave Solutions of Differential-Difference Equations**

Christopher Elmer, National Institute of Standards and Technology, Gaithersburg; and Erik S. Van Vleck, Organizer

**11:00-11:25 Mosaic Solutions and Entropy for Spatially Discrete Cahn-Hilliard Equations**

K. A. Abell and Anthony R. Humphries, University of Sussex, Brighton, United Kingdom; and Erik S. Van Vleck, Organizer

**11:30-11:55 Crystallographic Pinning: Direction Dependent Traveling Waves in Higher Dimensional Lattices**

John Mallet-Paret, Brown University

Monday, May 24

**MS18****Nonlinear Evolution, Separatrix Splitting, and Chaos in Dynamical Systems**

10:00 AM-12:00 PM

Room: *Superior A*

This minisymposium will focus on singular perturbation methods used in the analysis of the nonlinear behavior of complicated dynamical systems. These methods include, but are not limited to, reductive perturbative techniques and exponential asymptotics. The speakers will discuss the scope of the current formulations, including both avenues of further development, as well as limitations and possible alternative approaches, associated techniques for the identification and characterization of chaotic/turbulent solutions, and applications to nonlinear optics, astrophysical and space plasmas, classical dynamics, and general relativity.

**Organizer:** S. Roy Choudhury  
*University of Central Florida*

**10:00-10:25 Onset of Chaos in Singularly Perturbed Systems**

Alexander Tovbis, University of Central Florida

**10:30-10:55 Nonlinear Evolution and Chaos in the Kelvin-Helmholtz Instability of High Velocity Anisotropic Shear Layers**

Kevin G. Brown, University of Central Florida, and S. Roy Choudhury, Organizer

**11:00-11:25 Speaker and title to be announced****11:30-11:55 Speaker and title to be announced**

Monday, May 24

**MS19****Flows of Liquid Crystalline Polymers**

10:00 AM-12:00 PM

Room: *Superior B*

Liquid crystalline polymer (LCP) materials have been widely used in industrial and military applications. Modeling of the complex flows and characterization of the materials needs an effort across multiple disciplines ranging from model building to large-scale computation and analysis of complex dynamics. The participants in this minisymposium will present new molecular models for semi-flexible LCPs, a new continuum mechanical theory for nematic elastomers, kinetic theory for LCPs, analytical and numerical analysis on phase transitions in liquid crystal materials, modeling and computation of complex flows and formation of textures and defects in LCP flows. The study of LCP flows has come to the point where sophisticated computational and dynamical system tools are indispensable. The purpose of the minisymposium is therefore to enhance interactions among the active researchers.

**Organizer:** Qi Wang  
*Indiana University, Purdue University*

**10:00-10:25 Direct Numerical Simulation of Nematic Textures: Phase Transitions and Shearing Flows**

Alejandro D. Rey, McGill University, Montréal, Canada

**10:30-10:55 Modeling of the Smectic A - Nematic Phase Transition**

M. Carme Calderer, Pennsylvania State University

**11:00-11:25 Kinetic Models of Polymer-Liquid Crystal Systems**

Weinan E and Cyrill Muratov, Courant Institute of Mathematical Sciences, New York University

**11:30-11:55 Viscoelasticity of Solutions of Semi-Flexible Polymers**

David Morse, University of Minnesota, Minneapolis

Monday, May 24

## **MS20**

### **Stability and Bifurcations of Relative Equilibria: Theory**

**10:00 AM-12:00 PM**

*Room: White Pine*

Relative equilibria are trajectories of dynamical systems which are stationary modulo a group action. They include steady rotations of physical systems about fixed axes without changes of 'shape' and are of considerable interest in areas as diverse as N-body problems in celestial mechanics, molecules, systems of point vortices, multibody mechanics and rotating fluid masses. Some of these applications will feature in other (proposed) minisymposia at this conference. This session will be devoted to recent theoretical developments which improve our understanding of the stability properties and bifurcations of relative equilibria and underpin new computational techniques for applications.

**Organizers:** **Mark Roberts**

*University of Warwick, Coventry, United Kingdom*

**James Montaldi**

*Université de Nice, Valbonne, France*

#### **10:00-10:25 Stabilizing and Destabilizing Effects of Dissipation on Manifolds of Relative Equilibria**

Gianne Derk, University of Surrey, United Kingdom

#### **10:30-10:55 Mechanics on Homogenous Spaces**

Andrew Lewis, Queen's University, Kingston, Canada

#### **11:00-11:25 On Relative Normal Modes**

Eugene Lerman and T. Tokieda, University of Illinois, Urbana-Champaign

#### **11:30-11:55 Bifurcations from Symmetric Relative Equilibria**

Debra Lewis, University of California, Santa Cruz

Monday, May 24

## **Lunch**

**12:00 PM-1:30 PM**

Attendees are on their own.



Monday, May 24

## **IP4**

### **Life at the Boundary of Chaos Theory and Nonequilibrium Statistical Mechanics**

**1:30 PM-2:30 PM**

*Room: Ballrooms I, II & III*

*Chair: Mary Silber, Northwestern University*

The last decade or so has seen a strong surge of interest in the applications of dynamical systems theory to problems of interest to workers in nonequilibrium statistical mechanics. Unexpected relations have been discovered between transport coefficients, which appear in the macroscopic equations of fluid dynamics, and the Lyapunov exponents, Kolmogorov-Sinai entropies, and other quantities which characterize chaotic processes in the underlying microscopic dynamics. Stimulated by these relations, workers have developed methods to compute dynamical quantities, based on familiar techniques in statistical mechanics. The speakers will discuss these results and some important new theorems, such as the Gallavotti-Cohen fluctuation theorem, and the conjugate pairing rule for Lyapunov exponents. He will also mention some very interesting issues relating to the applications of SRB and related measures to entropy production and Green-Kubo formulae for transport coefficients.

**J. Robert Dorfman**

*Institute for Physical Science and Technology University of Maryland, College Park*

Monday, May 24

## **Coffee**

**2:30 PM-3:00 PM**



*Location: Ballroom Lobby*

**3:00 PM-5:00 PM**  
**Concurrent Sessions**

Monday, May 24

## **MS21**

### **Embeddings and Control — Part I of II**

**3:00 PM-5:00 PM**

*Room: Ballroom I*

For Part II, see MS26

For many experimental setups, no mathematical model is available. Embedding Techniques (introduced by Ruelle and Takens and made dynamic by Eckmann-Ruelle and Sano-Sawada) allow the reconstruction of the attractor numerically from the data. But these techniques are only the beginning. The problem is how can we create more reliable, more useful reconstructions. Can we compute Lyapunov exponents reliably? How many? Given a reconstruction (and no model), can (small) feedback controls be used to control the dynamics of the experiment? The idea is to select unstable trajectories of the system and use feedback control to stabilize these orbits.

**Organizer: James A. Yorke**

*University of Maryland, College Park*

#### **3:00-3:25 Visualization, Identification and Control of Chaos in Biological Systems**

William L. Ditto, Georgia Institute of Technology

#### **3:30-3:55 Nonlinear Prediction, Filtering and Control of Chemical Systems from Time Series**

Kenneth Showalter and Valery Petrov, West Virginia University

#### **4:00-4:25 Influence of Noise on Control of Chaotic Lasers**

Rajarshi Roy, Georgia Institute of Technology

#### **4:30-4:55 Controlling and Synchronizing Space Time Chaos**

Stefano Boccaletti, University of Navarra, Pamplona, Spain; F. Tito Arecchi and Jean Bragard, Istituto Nazionale di Ottica, Florence, Italy

Monday, May 24

## MS22

### Networks of Oscillators

3:00 PM-5:00 PM

*Room: Ballroom II*

Networks of nonlinear oscillators arise in many branches of science and engineering. They also pose fascinating mathematical problems that link dynamical systems theory to statistical mechanics, graph theory, and distributed computation. This minisymposium surveys recent developments in oscillator networks. The topics run the gamut from traditional with a twist (new bifurcation scenario in injection-locked lasers), to cutting-edge contemporary (phase locking and signal encoding in neural nets), to offbeat (why "six degrees of separation" may be much more than a curiosity of social networks).

**Organizers:** Steven H. Strogatz

*Cornell University*

**Paul C. Bressloff**

*Loughborough University, United Kingdom*

**3:00-3:25 Synchronization of Pulse-Coupled Oscillators with Delays**

Paul C. Bressloff, Organizer

**3:30-3:55 Population Coding and Noise Shaping in Spiking Neurons**

Carson C. Chow, University of Pittsburgh

**4:00-4:25 Dynamics of a Solid-State Laser with Injection**

Steven H. Strogatz, Organizer

**4:30-4:55 Small Worlds: The Dynamics of Networks Between Order and Randomness**

Duncan J Watts, The Santa Fe Institute

Monday, May 24

## MS23

### Mathematical and Computational Issues in Dynamics and Turbulence

3:00 PM-5:00 PM

*Room: Ballroom III*

The mathematics of rotating and stratified flows, particularly the reduced systems that emerge from asymptotic analyses, have played an important role in developing useful conceptual frameworks, especially in theoretical and numerical calculations. The minisymposium will aim to establish rigorous results on the dynamics of such flows and focus attention on problems that require careful mathematical analysis and numerical algorithms. The speakers in this session will focus on theoretical issues.

**Organizers: Basil Nicolaenko and Alex Mahalov**

*Arizona State University*

**3:00-3:25 Geometric Approximation Methods in Ocean Modeling**

Darryl D. Holm, Los Alamos National Laboratory

**3:30-3:55 On the Algebra of the Curl Operator for Euler and Navier-Stokes Equations**

Ciprian Foias, Indiana University, Bloomington

**4:00-4:25 Fast Singular Oscillating Limits of Stably Stratified Three-Dimensional Euler-Boussinesq Equations**

Anatoli Babin, University California, Irvine; Alex Mahalov and Basil Nicolaenko, Organizers

**4:30-4:55 Monge-Ampère Equations in Balanced Models**

Ian Roulstone, United Kingdom Meteorological Office, Berkshire, United Kingdom

Monday, May 24

## MS24

### Qualitative Analysis of Nonlinear Partial Differential Equations

3:00 PM-5:00 PM

*Room: Superior A*

The qualitative theory of nonlinear PDEs has developed considerably over the last few years. The dynamical systems theory of dissipative nonlinear PDEs allow one to solve problems where the dynamics settle to a low-dimensional set of solutions and to control these dynamics. Problems where the dynamics remain high-dimensional offer more challenge, but the elements of a high-dimensional dynamical system theory for nonlinear PDEs are beginning to emerge. In this session, the speakers will explore these emerging techniques and their application.

**Organizer: Björn Birnir**

*University of California, Santa Barbara*

**3:00-3:25 Emergence of Channelized Drainage Patterns and Landsurface Scalings**

Terence R. Smith, University of California, Santa Barbara; Björn Birnir, Organizer; and George E. Merchant, University of California, Santa Barbara

**3:30-3:55 Well-Posedness and Ill-Posedness for the Initial Value Problem of Nonlinear Dispersive Equations**

Gustavo Ponce, University of California, Santa Barbara; Carlos E. Kenig, University of Chicago; and Luis Vega, Universidad del País Vasco, Bilbao, España

**4:00-4:25 The Evolution of Compactly Supported Planar Vorticity**

Thomas C. Sideris, University of California, Santa Barbara; and Dragos Iftimie, Université de Rennes 1, France

**4:30-4:55 Speaker and title to be announced**

Monday, May 24

## **MS25**

### **Chaos and Irreversibility**

**3:00 PM-5:00 PM**

*Room: Maybird*

This minisymposium aims at augmenting the plenary talk by J. Robert Dorfman on the relation between transport properties of many-particle systems and their underlying chaotic dynamics. The speakers in this minisymposium will discuss the possibility of experimentally observing chaos in many article systems, and the modelling of thermodynamic transport properties by spatially extended chaotic maps of the plane. Special attention is devoted to entropy production fluctuations in nonequilibrium steady states, and to recent results of computer simulations of many-particle systems and turbulence.

**Organizer: Tamás Tél**

*Eötvös University, Budapest, Hungary*

#### **3:00-3:25 Probing the Microscopic Chaos of a Fluid of Particles with a Brownian Test Particle**

Pierre Gaspard, Université Libre de Bruxelles, Belgium

#### **3:30-3:55 Time Reversibility, Entropy Balance, and the Green-Kubo Relations**

Jürgen Vollmer, Universität GH Essen, Germany

#### **4:00-4:25 Multifractal Phase Space Densities for Stationary Nonequilibrium Systems**

Harald A. Posch, Universität Wien, Austria

#### **4:30-4:55 Hyperbolicity and KAM Bottles in the Driven Lorentz Gas**

Maciej Wojtkowski, University of Arizona

Monday, May 24

## **CP10**

### **Geophysical Flows**

**3:00 PM-5:00 PM**

*Room: Magpie A/B*

*Chair: Ferdinand Verhulst, University of Utrecht, The Netherlands*

#### **3:00-3:15 A Low-Dimensional Climate Model I**

Ferdinand Verhulst, University of Utrecht, The Netherlands

#### **3:20-3:35 A Low Dimensional Climate Model II**

Lennaert van Veen, University of Utrecht, The Netherlands

#### **3:40-3:55 Global Bifurcation in a Simple Ocean Model**

B. T. Nadiga and Benjamin Luce, Los Alamos National Laboratory

#### **4:00-4:15 Low-Dimensional Atmospheric Models at Various Truncations**

Daan Crommelin, Royal Netherlands Meteorological Institute, The Netherlands

#### **4:20-4:35 Finite Difference Balanced Models**

Don Jones, Arizona State University

#### **4:40-4:55 Reversals and on-off Intermittency in the Dynamics of the Convective Dynamo**

Iuliana Oprea, University of Bucharest, Romania and Arizona State University

Monday, May 24

## **CP11**

### **Granular Flows**

**3:00 PM-4:20 PM**

*Room: Wasatch A/B*

*Chair: Troy Shinbrot, Rutgers University*

#### **3:00-3:15 Spontaneous Chaotic Granular Mixing**

Troy Shinbrot, Albert W. Alexander, and Fernando J. Muzzio, Rutgers University

#### **3:20-3:35 About Motion of Spherical Particles on a Surface**

Ljubinka (Lou) Kondic, Meenakshi Dutt, and Robert P. Behringer, Duke University

#### **3:40-3:55 Molecular Dynamic Simulations of Clusters in Sheared Granular Materials**

Elizabeth D. Liss and Benjamin J. Glasser, Rutgers University

#### **4:00-4:15 A Kinetic Model for Granular Media**

Xinzhong Chen and Edward A. Spiegel, Columbia University

**Monday, May 24**

## **CP12**

### **Physiology**

**3:00 PM-5:00 PM**

*Room: Superior B*

*Chair: James Lawry, California Academy of Sciences, San Francisco*

#### **3:00-3:15 Respiration by Turbulant Diffusion in Frogs**

James Lawry, California Academy of Sciences, San Francisco

#### **3:20-3:35 Modelling the Control of Ovulation in Terms of Gonadotropin Receptors in Granulosa Cells**

A. Chavez-Ross and J. Stark, University College London, United Kingdom; and S. Franks, Imperial College of Science Technology and Medicine, London, United Kingdom

#### **3:40-3:55 Subcellular Mechanisms for the Regularization of Neural Bursting Activity**

Pablo Varona, Joaquin J. Torres, Ramon Huerta, Henry D. I. Abarbanel and Mikhail I. Rabinovich, University of California, San Diego

#### **4:00-4:15 The Mechanics of Lung Tissue Under High-Frequency Lung Ventilation**

Markus R. Owen, Mark A. Lewis, and David J. Eyre, University of Utah

#### **4:20-4:35 Cardiorespiratory Interaction in Anesthesia**

Aneta Stefanovska and Mario Hozic, University of Ljubljana, Slovenia; and Hermann Haken, Universität Stuttgart, Germany

#### **4:40-4:55 Dynamics of Human Blood Distribution System**

Maja Bracic and Aneta Stefanovska, University of Ljubljana, Slovenia

**Monday, May 24**

## **CP13**

### **Delay Equations**

**3:00 PM-4:40 PM**

*Room: Golden Cliff*

*Chair: Thomas Erneux, Universiteit Libre de Bruxelles, Belgium*

#### **3:00-3:15 Delay-Differential Equations with a Large Delay: Application to Semiconductor Laser Instabilities**

Didier Pieroux and Thomas Erneux, Universiteit Libre de Bruxelles, Belgium

#### **3:20-3:35 The Construction of the Asymptotic Solutions of the System of Differential Equations with Deviating Argument**

Vladimir Domnytsky, Montréal, Canada

#### **3:40-3:55 On the Stability of Neutral Functional Differential Equations**

Wim Michiels, Dirk Roose, and Koen Engelborghs, Catholique Universiteit Leuven, Belgium

#### **4:00-4:15 Numerical Methods for Delay Differential Equations: New Approach, Software Package, Applications**

Arkadii V. Kim, Seoul National University, Korea; Oh Bok Kwon, Kyung Bok College, Kyung-Kido, Seoul, Korea; Vladimir G. Pimenov, Ural State University, Ekaterinburg, Russia

#### **4:20-4:35 Existence of Periodic Solutions for a State Dependent Delay Differential Equation**

P. Magal, Faculte des Sciences et Techniques, Le Havre, France; and O. Arino, Université de Pau, France

**Monday, May 24**

## **CP14**

### **Hamiltonian Systems**

**3:00 PM-5:00 PM**

*Room: White Pine*

*Chair: James D. Meiss, University of Colorado, Boulder*

#### **3:00-3:15 Quadratic Volume Preserving Maps: Normal Forms and Dynamics**

James D. Meiss, University of Colorado, Boulder; and Hector E. Lomeli, Instituto Tecnológico Autonomo de México

#### **3:20-3:35 Size Matters in Small One-Dimensional Lattices**

Chih-Yu Lin and Seth Lichten, Northwestern University; Sung N. Cho and Christopher G. Goedde, DePaul University

#### **3:40-3:55 Stability Exponents and Separation of Variables**

William E. Wiesel, Air Force Institute of Technology/ENY

#### **4:00-4:15 Vanishing Twist Near Resonances in Symplectic Maps**

Holger R. Dullin, David G. Sterling, and James D. Meiss, University of Colorado, Boulder

#### **4:20-4:35 Volume-Preserving Reduction by Symmetry**

Nathan Frazier and Igor Mezic, University of California, Santa Barbara

#### **4:40-4:55 Properties of Integrability of Systems in Terms of Transcendental Functions**

Maxim V. Shamolin, Lomonosov Moscow State University, Russia

Monday, May 24

## Business Meeting

SIAM Activity Group on  
Dynamical Systems  
(SIAG/DS)

5:00 PM-6:00 PM

*Room: Ballroom I*

*Chair: Shui-Nee Chow, Georgia  
Institute of Technology, and National  
University of Singapore*

Monday, May 24

## Dinner

6:00 PM

Attendees are on their own.



## Tuesday, May 25

For papers with multiple authors,  
*the speaker is shown in italics*,  
if known at press time.

Tuesday, May 25

## Registration Open

7:30 AM-4:00 PM

*Location: Ballroom Lobby*

Tuesday, May 25

## IP5

### Attractors in Evolutionary Equations

8:30 AM-9:30 AM

*Room: Ballrooms I, II & III*

*Chair: Peter Bates, Brigham Young  
University*

The speaker will discuss conditions for the existence of compact global attractors. He will present specific examples for which there is much known about the flow on the attractor, and will emphasize parabolic and hyperbolic PDEs.

**Jack Hale**

*School of Mathematics, Georgia  
Institute of Technology*

Tuesday, May 25

## Coffee

9:30 AM-10:00 AM



*Location: Ballroom Lobby*

10:00 AM-12:00 PM  
Concurrent Sessions

Tuesday, May 25

## MS26

### Embeddings and Control — Part II of II

10:00 AM-12:00 PM

*Room: Ballroom I*

For Part I, see MS21

For many experimental setups, no mathematical model is available. Embedding Techniques (introduced by Ruelle and Takens and made dynamic by Eckmann-Ruelle and Sano-Sawada) allow the reconstruction of the attractor numerically from the data. But these techniques are only the beginning. The problem is how can we create more reliable, more useful reconstructions. Can we compute Lyapunov exponents reliably? How many? Given a reconstruction (and no model), can (small) feedback controls be used to control the dynamics of the experiment? The idea is to select unstable trajectories of the system and use feedback control to stabilize these orbits.

**Organizer: James A. Yorke**

*University of Maryland, College Park*

10:00-10:25 Embeddings, Fractals  
and Making Sense of Digital  
Communications

*David S. Broomhead, J. P. Huke, and  
Mark R. Muldoon, University of  
Manchester Institute of Science and  
Technology, United Kingdom*

10:30-10:55 Spurious Lyapunov  
Exponents in Attractor  
Reconstruction

*Timothy D. Sauer, George Mason  
University*

11:00-11:25 When Embeddings  
Perfectly Reflect the Dynamics

*James A. Yorke, Organizer; Josh Tempkin,  
University of Maryland, College Park;  
and Timothy D. Sauer, George Mason  
University*

11:30-11:55 Projections, Embedding,  
and Fractal Dimensions

*Brian Hunt, University of Maryland,  
College Park; and Vadim Yu. Kaloshin,  
Princeton University*

Tuesday, May 25

## **MS27**

### **Vibrating Granular Media**

**10:00 AM-12:00 PM**

*Room: Ballroom II*

Granular media are systems of macroscopic particles that interact mainly through contact forces. Granular media abound in nature and industry, but are not well understood. Recent laboratory experiments on granular media in oscillated containers have revealed a variety of collective phenomena—heaping, segregation, compaction, convection, spatial patterns, and clustering. The speakers in this minisymposium will describe the phenomena and molecular dynamics simulations developed to understand them. The simulations assume that the particles obey Newton's laws and that energy is dissipated in collisions. While simulations and pde models provide many open questions.

**Organizer: Harry L. Swinney**  
*University of Texas, Austin*

**10:00-10:25 Energy Flows, Segregation, and Collapse in Vibrated Granular Media**

Stefan Luding, University of Stuttgart, Germany

**10:30-10:55 Compaction and Thermodynamics in Vibrated Granular Media**

Sidney R. Nagel, University of Chicago, Illinois

**11:00-11:25 Stability and Dynamics of Vertically and Horizontally Shaken Sand**

Robert P. Behringer, L. Kondic, S. Tennakoon, and R. Hartley, Duke University

**11:30-11:55 Wave Patterns in Vertically Oscillated Granular Media**

Chris Bizon, University of Texas, Austin

Tuesday, May 25

## **MS28**

### **Nonlinear Advection Diffusion Equations: Analysis and Applications**

**10:00 AM-12:00 PM**

*Room: Ballroom III*

The fundamental equations of fluid dynamics present some profound challenges. Extracting rigorous predictions with physical relevance from the equations of motion is a difficult task, but substantial progress has been achieved in recent years. The speakers in this minisymposium will focus on recent mathematical results for the incompressible Navier-Stokes and related equations and their relation to experiments and applications.

**Organizers: Charles R. Doering**  
*University of Michigan, Ann Arbor*

**Peter Constantin**  
*University of Chicago, Illinois*

**10:00-10:25 Energy Dissipation Rate in Shear Driven Turbulence**

Xiaoming Wang, Iowa State University

**10:30-10:55 Dynamics and Blow Up for An Active Scalar**

Michael P. Brenner, Massachusetts Institute of Technology; Peter Constantin, Organizer; Leo P. Kadanoff, Alain Schenkel, and Shankar C. Venkataramani, University of Chicago, Illinois

**11:00-11:25 Scaling and Burning Velocity in Turbulent Combustion**

Peter Constantin, Organizer; Alexander Kiselev, and Leonid Ryzhik, University of Chicago, Illinois

**11:30-11:55 Towards a Variational Principle for the Navier-Stokes Equations**

Richard R. Kerswell, Bristol University, United Kingdom

Tuesday, May 25

## **MS29**

### **Bifurcations in Neuron Dynamics**

**10:00 AM-12:00 PM**

*Room: Magpie A/B*

Neural excitability, spiking, and bursting result from certain bifurcations of the membrane potential of the cell. Revealing these bifurcations in mathematical models and *in vivo* helps to understand and classify dynamical properties of neurons and their networks. The speakers in this minisymposium will discuss recent work on neurons and neuron network models.

**Organizer: Eugene M. Izhikevich**  
*Arizona State University*

**10:00-10:25 Adaptation and Synchrony in Neural Oscillators**

G. Bard Ermentrout, University of Pittsburgh

**10:30-10:55 Phantom Bursting in Pancreatic Beta Cells**

Richard Bertram and Joseph Previte, Pennsylvania State University; and Arthur Sherman, National Institutes of Health

**11:00-11:25 Propagating Activity Patterns in Thalamic Networks**

David Terman, Ohio State University

**11:30-11:55 Neural Excitability, Spiking, and Bursting**

Eugene M. Izhikevich, Organizer

Tuesday, May 25

## **MS30**

### **Invariant Manifolds, Foliations and Applications**

**10:00 AM-12:00 PM**

*Room: Wasatch A/B*

Invariant manifolds and foliations have become fundamental tools to study the qualitative properties of a flow or semiflow near invariant sets. They are extremely useful tracking the asymptotic behavior of solutions and providing coordinates in which systems of differential equations may be decoupled and normal forms derived. In many cases, they are useful for technical estimates which facilitate the study of bifurcation. In this minisymposium, the speakers will discuss a construction of periodic orbits for singularly perturbed systems, the existence of homoclinic orbits for singularly perturbed nonlinear Schrödinger equation, the existence and metastability of spiky solutions for reaction-diffusion systems with strong coupling, the motion of interacting spikes, and surface nucleation for the Ginzburg-Landau equations.

**Organizer: Kening Lu**  
*Brigham Young University*

#### **10:00-10:25 Periodic Orbits in Singularly Perturbed Systems**

Christopher K.R.T. Jones, Brown University

#### **10:30-10:55 Surface Nucleation of Superconductivity**

Xingbin Pan, Zhejiang University, Hangzhou, People's Republic of China; and Kening Lu, Organizer

#### **11:00-11:25 On Reaction-Diffusion Systems with Strong Coupling**

Juncheng Wei, The Chinese University of Hong Kong, Hong Kong, People's Republic of China

#### **11:30-11:55 Homoclinic Orbits for Singularly Perturbed NLS**

Chongchun Zeng, Courant Institute of Mathematical Sciences, New York University

Tuesday, May 25

## **MS31**

### **Nonlinear Dynamics in Communication: Coding, Channel Modeling and Secure Communications**

**10:00 AM-12:00 PM**

*Room: Golden Cliff*

A quick glance at the literature might suggest that the tools of modern nonlinear dynamics have only a few significant applications to communications, chiefly the Pecora-Carroll protocols for secure communication via chaotic synchronization. The speakers in this symposium will touch on synchronization, but will also explore a wider range of applications. They will discuss the use of dynamical systems to generate novel codes, the interplay between nonlinear time series analysis and cryptographic assault, and the self-similar structure of telephone traffic.

**Organizer: Mark R. Muldoon**  
*University of Manchester Institute of Science and Technology, United Kingdom*

#### **10:00-10:25 Codes for Spread Spectrum Applications Generated With Chaotic Dynamical Systems**

*Mark R. Muldoon, Organizer; J. P. Huke and David S. Broomhead, University of Manchester Institute of Science and Technology, United Kingdom*

#### **10:30-10:55 Chaos, Communications and Nonlinear Data Analysis**

*Ulrich Parlitz and Jochen Bröcker, Universität Göttingen, Germany*

#### **11:00-11:25 Improving the Robustness of Synchronized Chaotic Communication Systems**

*Chris Williams, Defence Evaluation Research Agency, Malvern, United Kingdom*

#### **11:30-11:55 Levy-Stable Distributions and Self-Similar Teletraffic Modeling**

*Stephen McLaughlin, University of Edinburgh, United Kingdom*

Tuesday, May 25

## **MS32**

### **Observation, Analysis and Modeling of Excitable Systems**

**10:00 AM-12:00 PM**

*Room: Maybird*

Various natural systems present excitable dynamical behavior, with excitability defined in terms of the systems response to perturbations. Such behavior can be found in biological systems, laser physics, and chemical reactions, among others. The combination of excitability with other dynamical processes gives rise to very particular behaviors. Diffusively coupled excitable systems generate some easily recognizable patterns. When subject to noise, excitable systems display a particular statistical behavior. In this minisymposium, the speakers will discuss the observation, analysis and modeling of different aspects of excitable systems with the aim of finding their underlying common features.

**Organizers: Silvina Ponce Dawson and Gabriel B. Mindlin**  
*Ciudad Universitaria, Buenos Aires, Argentina*

#### **10:00-10:25 Excitable Behavior in Semiconductor Lasers**

*Jorge L. Tredicce and M. Giudici, Université de Nice, Valbonne, France*

#### **10:30-10:55 Frequency Locked Patterns in a Periodically Perturbed Reaction-Diffusion System**

*Anna L. Lin, Valery Petrov, Alexandre Ardelea, Graham F. Carey, and Harry L. Swinney, University of Texas, Austin*

#### **11:00-11:25 Topological Structure of Noise Driven Excitable Systems**

*Gabriel B. Mindlin, Organizer; Manuel C. Eguia and Alejandro Yacomotti, Ciudad Universitaria, Buenos Aires, Argentina*

#### **11:30-11:55 Classifying Excitable Reaction-Diffusion Systems**

*Silvina Ponce Dawson, Organizer; and John E. Pearson, Los Alamos National Laboratory*

Tuesday, May 25

## MS33

### Patten Formation in the Cahn-Hilliard Model — Part I of II

10:00AM-12:00 PM

Room: Superior A

For Part II, see CP37

In the forty years since its introduction, the Cahn-Hilliard model has proved its ability to exhibit pattern formation and phase separation phenomena like those being observed in binary metallic alloys. Therefore, understanding the dynamical behavior of the model is of immediate interest in materials sciences. While existing mathematical results for the one-dimensional model provide a fairly complete picture of its rich dynamics, most of the current research focuses on the physically more relevant two- and three-dimensional models, as well as their discrete and multi-component counterparts. The talks in the minisymposium will cover a broad spectrum of these recent studies.

**Organizers:** Stanislaus Mauer-Paape  
*Georgia Institute of Technology*

**Thomas Wanner**  
*University of Maryland, Baltimore County*

**10:00-10:25 The Motion of the Bubble Towards the Boundary**  
Nicholas Alikakos, University of Tennessee, Knoxville

**10:30-10:55 Multi-Spike Solutions to the Cahn-Hilliard Equation**  
Peter Bates, Brigham Young University; and Giorgio Fusco, Università di L'Aquila, Italy

**11:00-11:25 Cascades of Instability In the Solutions of Vector-Valued Cahn-Hilliard Equations**  
David J. Eyre, University of Utah

**11:30-11:55 Pattern Formation in Gradient Systems**

*Paul Fife, University of Utah; and Michal Kowalczyk, Carnegie-Mellon University*

Tuesday, May 25

## MS34

### New Models and Analysis of Noise-Sensitive Dynamical Systems

10:00 AM-12:00 PM

Room: Superior B

This minisymposium addresses modeling of stochastic effects in applied problems and methods, such as statistical analysis, projection techniques, and asymptotic expansions, used to investigate these models. Systems with diffusion and jump noises are modeled with stochastic ordinary and partial differential equations. Probability densities describing the dynamics of noisy metastable interfaces are obtained from new models. Stochastic resonance in excitable systems, such as neuron firing, are measured with new tools. Diffusion in a randomly fluctuating potential can be controlled to optimize a nonzero steady-state current. Discrete and continuous models of boundary effects in random transport are examined for ionic channels.

**Organizers:** Rachel Kuske  
*University of Minnesota, Minneapolis*

**Malgorzata M. Klosek**  
*University of Wisconsin, Milwaukee*

**10:00-10:25 A Combined Molecular Dynamics and Diffusion Model for Single Proton Conduction Through Gramicidins**

Mark F. Schumaker, Washington State University

**10:30-10:55 Stochastic Resonance and Neuron Firing: Statistical Aspects**

Priscilla Greenwood, University of British Columbia, Vancouver, Canada

**11:00-11:25 Current In Sharp Additive Ratchets: Analysis and Exact Results**

Malgorzata M. Klosek, Organizer

**11:30-11:55 Models and Prediction for Noisy Interface Dynamics**

*Rachel Kuske, Organizer; and Michael Ward, University of British Columbia, Vancouver, Canada*

Tuesday, May 25

## MS35

### Stability and Bifurcations of Relative Equilibria: Applications

10:00 AM-12:00 PM

Room: White Pine

Relative equilibria arise in nature and in industry. For example, steady rotation of coupled rigid or deformable bodies and steady motions in fluid models are of interest to engineers, physicists, and chemists. The analysis of concrete examples elucidates the limitations of existing theoretical approaches and can bring to light unrecognized structures, leading to more general or efficient methodologies. The speakers in this minisymposium will focus on several specific applications and demonstrate mutually beneficial interaction between theory and example.

**Organizer:** Debra K. Lewis  
*University of California, Santa Cruz*

**10:00-10:25 Nekhoroshev-Stability of Elliptic (Relative) Equilibria and the Riemann Ellipsoids**

Francesco Fasso, Università di Padova, Italy

**10:30-10:55 Stabilization of Relative Equilibria**

Jerrold E. Marsden, California Institute of Technology

**11:00-11:25 Drift of Certain 4-Vortex Relative Equilibria**

George W. Patrick, University of Saskatchewan, Saskatoon, Canada

**11:30-11:55 A Generalization of Riemann's Theorem for Rotating Fluid Masses**

Mark Roberts, University of Warwick, United Kingdom

Tuesday, May 25

## Lunch

12:00 PM-1:30 PM

Attendees are on their own.



Tuesday, May 25

## IP6

### Finite Element Analysis of Nonsmooth Contact

1:30 PM-2:30 PM

*Room: Ballrooms I, II & III*

*Chair: Jerrold Marsden, California Institute of Technology*

The objective of this presentation is to describe the development of robust contact algorithms capable of dealing with multibody nonsmooth contact geometries for which neither normals nor gap functions can be defined. These algorithms have many applications, for example to granular flows and to brittle solids undergoing fragmentation. Dynamic fragmentation often results in the formation of large numbers of fragments which undergo complex collision sequences before they eventually scatter. A robust and systematic procedure is therefore required in order to ascertain the precise sequence of collisions undergone by the bodies. The speaker will refer to contact processes such as described, involving the simultaneous interaction between many angular bodies, as nonsmooth contact. A suitable mathematical framework for dealing with this class of problems is furnished by nonsmooth analysis. However, it should be noted that the admissible sets which arise in contact problems are generally nonconvex, which precludes the direct application of convex analysis. The speaker will discuss some algorithms in simulations of fracture and fragmentation, and demonstrate their good performance.

**Michael Ortiz**

*Graduate Aeronautical Laboratories  
California Institute of Technology*

Tuesday, May 25

## Coffee

2:30 PM-3:00 PM



*Location: Ballroom Lobby*

3:00 PM-5:00 PM  
Concurrent Sessions

Tuesday, May 25

## CP15

### Data Analysis I/ Spatiotemporal

3:00 PM-5:00 PM

*Room: Ballroom I*

*Chair: Thomas Schreiber, University of Wuppertal, Germany*

#### 3:00-3:15 Locating Information Sources in Spatiotemporal Data

Thomas Schreiber, University of Wuppertal, Germany; and Jochen Arnhold, John von Neumann Institute for Computing (NIC), Forschungszentrum Jülich, Germany

#### 3:20-3:35 Identification and Characterization of High-Dimensional Chaos

Martin J. Bünner and Antonio Politi, Istituto Nazionale di Ottica, Florence, Italy; Rainer Hegger and Holger Kantz, Max-Planck Institut für Physik Komplexer Systeme, Dresden, Germany

#### 3:40-3:55 Lyapunov Spectra from Sub-System Information in Spatiotemporal Systems: A Time-Series Perspective

R. Carretero-Gonzalez, S. Orstavik and J. Stark, University College London, United Kingdom; J. Huke and D.S. Broomhead, University of Manchester Institute of Science and Technology, United Kingdom

#### 4:00-4:15 Low-Dimensional Approximations to High-Dimensional Systems

Stephen P. Meacham, Atmospheric and Environmental Research Inc.

#### 4:20-4:35 Spatiotemporal Chaos in Yttrium Iron Garnet Films

Christopher L. Goodridge, Frederic Rachford, Thomas Carroll and Louis Pecora, U.S. Naval Research Laboratory

#### 4:40-4:55 Deterministic Structure in Data from a Free Running Neuronal Ensemble: A Comparison of Nonlinear Tests for Determinism

Joseph T. Francis, George Mason University and George Washington University; and Paul So, George Mason University

Tuesday, May 25

## CP16

### Mathematical Biology I

3:00 PM-5:00 PM

*Room: Ballroom II*

*Chair: James F. Selgrade, North Carolina State University*

#### 3:00-3:15 Dynamical Behavior of a Discrete, Migration Model with Density-Dependent Selection

James F. Selgrade, North Carolina State University

#### 3:20-3:35 Urn Models, Replicator Equations and Genetic Drift

Sebastian J. Schreiber, Western Washington University

#### 3:40-3:55 Nonlinear Stability of Age-dependent Population Dynamics

C. B. Clemons, S. I. Hariharan and D. D. Quinn, The University of Akron

#### 4:00-4:15 Complex Co-evolutionary Dynamics in Simple Ecological Foodwebs

James W. Haefner, Utah State University

#### 4:20-4:35 Period-Doubling Bifurcation Leading to Chaos in an Ecological Model

A. Aziz Alaoui, Université Le Havre, France

#### 4:40-4:55 Persistence and Extinction in Two Species Reaction-Diffusion Systems with Delays

Shigui Ruan, Dalhousie University; and Xiao-Qiang Zhao, Academia Sinica, China

Tuesday, May 25

**CP17****Coupled Oscillators I****3:00 PM-5:00 PM***Room: Ballroom III**Chair: William F. Langford, University of Guelph, Canada***3:00-3:15 Coupled Oscillators Near Strong Resonances**

William F. Langford, University of Guelph, Canada

**3:20-3:35 From Mode-Locking to Chaos in Integrate-and-Fire Dynamical Systems**

Stephen Coombes and Paul C. Bressloff, Loughborough University, Leicestershire, United Kingdom

**3:40-3:55 Effect of Noise on Phase Synchronization of Coupled Chaotic Oscillators**

Victor Andrade and Ying-Cheng Lai, University of Kansas, Lawrence

**4:00-4:15 Observability of Lag Synchronization of Coupled Chaotic Oscillators**

Saeed Taherion and Ying-Cheng Lai, University of Kansas, Lawrence

**4:20-4:35 Extreme Parametric Uncertainty and Instant Chaos and In Coupled Structural Dynamics**

Ira B. Schwartz, Yvette K. Wood and Ioannis T. Georgiou, U.S. Naval Research Laboratory

**4:40-4:55 Chaotic Oscillations in the Duffing Oscillator with High- and Low-Frequency External Forcing**

Dmytro V. Shygimaga and Dmytro M. Vavriv, Institute of Radio Astronomy, Kharkov, Ukraine

Tuesday, May 25

**CP18****Patterns I and Anisotropic I****3:00 PM-4:40 PM***Room: Magpie A/B**Chair: Gerhard Dangelmayr, Colorado State University***3:00-3:15 Hopf Bifurcation in Anisotropic Systems**

Gerhard Dangelmayr, Colorado State University

**3:20-3:35 Scroll Wave Twist in the Presence of Rotational Anisotropy**

Sima Setayeshgar, California Institute of Technology; and Alain S. Karma, Northeastern University

**3:40-3:55 Pattern Formation in Axial Compressors**

Gregory S. Hagen and Igor Mezic, University of California, Santa Barbara

**4:00-4:15 Dynamics of Spiral Waves in Weak Inhomogeneity**

Matthew Hendrey, Edward Ott and Thomas M. Antonsen, Jr., University of Maryland, College Park

**4:20-4:35 Spiral Instabilities in Chemical and Biological Reaction-Diffusion Systems**

Michal Or-Guil and Markus Bar, Max-Planck Institut für Physik Komplexer Systeme, Dresden, Germany; and Martin Falcke, University of California, San Diego

Tuesday, May 25

**CP19****Control I****3:00 PM-5:00 PM***Room: Wasatch A/B**Chair: Ioana Triandaf, U. S. Naval Research Laboratory***3:00-3:15 Quality Factor Control of Lasing Microcavities**

Ioana Triandaf and Ira B. Schwartz, U. S. Naval Research Laboratory

**3:20-3:35 Targeting Applying  $\epsilon$ -Bounded Orbit Correction Perturbations**

Murilo S. Baptista, University of Maryland, College Park

**3:40-3:55 Combinatorial Optimization by Piecewise Continuous Dynamical Systems**

Jens Starke, University of Heidelberg, Germany

**4:00-4:15 Micro-Active Control of a Planar Jet**

Thomas Peacock and Elizabeth Bradley, University of Colorado, Boulder

**4:20-4:35 Driving Trajectories in Complex Systems**

Elbert E. N. Macau, INPE-Brazilian Institute for Space Research, São Jose dos Campos, Brasil; and Celso Grebogi, University of Maryland, College Park

**4:40-4:55 Double Bracket Energy Sinks and Stabilization of Principal Axis Rotations**

Charles P. Coleman, Joseph C. Wilson Center for Research and Technology, Xerox Corporation

Tuesday, May 25

## **CP20**

### **Chaotic Maps I**

**3:00 PM-5:00 PM**

*Room: Golden Cliff*

*Chair: John R. Terry, Georgia Institute of Technology*

#### **3:00-3:15 Weak Attractors and Basin Riddling**

Peter Ashwin, University of Surrey, United Kingdom; *John R. Terry, Georgia Institute of Technology*

#### **3:20-3:35 Dynamical Systems Methods Applied to Polynomial Factorization Families: A Study of Chaotic Attractors**

Lora Billings, University of Delaware

#### **3:40-3:55 Chaotic Sets Explosions: A Conjecture**

*Carl Robert, University of Maryland, College Park; Kathleen T. Alligood, George Mason University; Edward Ott and James A. Yorke, University of Maryland, College Park*

#### **4:00-4:15 Pseudo-Riddling in Chaotic Systems**

Roman Buny and *Ying-Cheng Lai, University of Kansas, Lawrence; and Celso Grebogi, University of Maryland, College Park*

#### **4:20-4:35 Life Expectancy Estimations of Transient Chaos**

*Gabor Stépan and Gabor Csernák, Technical University of Budapest, Hungary*

#### **4:40-4:55 The Topological Pressure for a Kind of Kicked Integrable Systems**

J. Ruben Luevano, Universidad Autónoma Metropolitana Azcapotzalco, México

Tuesday, May 25

## **CP21**

### **Solitons I**

**3:00 PM-5:00 PM**

*Room: Maybird*

*Chair: Prabir Daripa, Texas A&M University, College Station*

#### **3:00-3:15 Numerical and Theoretical Studies of Some Model Equations for Bi-Directional Propagation of Nonlinear Dispersive Long Waves**

Prabir Daripa, Texas A&M University, College Station

#### **3:20-3:35 Soliton Metamorphosis**

*E. Infeld and G. Rowlands, University of Warwick, United Kingdom*

#### **3:40-3:55 Internal Modes and Their Radiation Damping in Vector Solitons of Coupled Nonlinear Schrödinger Equations**

Jianke Yang, University of Vermont

#### **4:00-4:15 The Secret Lives of Kinks**

*Grant Lythe and Salman Habib, Los Alamos National Laboratory*

#### **4:20-4:35 Multiple Pulses in Dispersive Quadratic Media**

Alice C. Yew, The Ohio State University

#### **4:40-4:55 Travelling Waves in a Model for Water Waves**

L.A. Peletier and *A. I. Rotariu, University of Leiden, The Netherlands*

Tuesday, May 25

## **CP22**

### **Numerics I**

**3:00 PM-5:00 PM**

*Room: Superior A*

*Chair: R. D. Skeel, University of Illinois, Urbana*

#### **3:00-3:15 Nonlinear Stability Analysis of Area-Preserving Integrators**

*R. D. Skeel, University of Illinois, Urbana; and K. Srinivas, Microsoft Corporation*

#### **3:20-3:35 The Dynamics of Adaptive Timestepping ODE Solvers**

Harbir Lamba, George Mason University

#### **3:40-3:55 Numerical Solutions of a Lienard-type Equation**

*Abba B. Gumel, The Fields Institute for Research in Mathematical Sciences, Toronto, Canada; and E. H. Twizell, Brunel University, Middlesex, United Kingdom*

#### **4:00-4:15 Using Differential Equation Solvers to Compute the Stable Manifold**

*Myong-Hee Sung and James A. Yorke, University of Maryland, College Park; and Peter Calabrese, Cornell University*

#### **4:20-4:35 On Computational Aspects of Computer-Assisted Proofs of Chaos in ODEs**

*Piotr Zgliczynski, Georgia Institute of Technology; and Marian Mrozek, Jagiellonian University, Krakow, Poland*

#### **4:40-4:55 Numerical Continuation of Periodic Orbits in Symmetric Hamiltonian Systems**

*J. Galan and E. Freire, Escuela Superior de Ingenieros de Sevilla, España; and E. J. Doedel, Concordia University, Montréal, Canada*

Tuesday, May 25

## CP23

### Transport I

3:00 PM-5:00 PM

*Room: Superior B*

*Chair: Vered Rom-Kedar, Courant Institute of Mathematical Sciences, New York University*

#### 3:00-3:15 Frequency Dependence of Chaotic Transport in the Presence of Diffusion

*Vered Rom-Kedar, Courant Institute of Mathematical Sciences, New York University; and Andrew C. Poje, Brown University*

#### 3:20-3:35 Transport in Action-Angle-Angle Maps

*Igor Mezic, University of California, Santa Barbara*

#### 3:40-3:55 Mixing In Compressible Flows

*Franz David Betz and Igor Mezic, University of California, Santa Barbara*

#### 4:00-4:15 Matrix Approaches to Mixing Rates

*Rua Murray, University of Victoria, Canada*

#### 4:20-4:35 Passive Tracer Dispersion in Fluids

*Jinqiao Duan, Clemson University*

#### 4:40-4:55 Advection of Finite Size Neutral Particles and Control of Hamiltonian Chaos

*Julian H. E. Cartwright, CSIC-Universidad de Granada, España; and Oreste Piro, Universitat de les Illes Balears, Palma de Mallorca, España*

Tuesday, May 25

## CP24

### Partial Differential Equations I

3:00 PM-5:00 PM

*Room: White Pine*

*Chair: J. Patrick Wilber, University of Maryland, College Park*

#### 3:00-3:15 Global Attractors for a Degenerate Equation from Viscoelasticity

*J. Patrick Wilber and Stuart S. Antman, University of Maryland, College Park*

#### 3:20-3:35 Asymptotic Analysis of a Spike-Type Solution of an Elliptic Equation

*Leonid V. Kalachev, University of Montana*

#### 3:40-3:55 Elliptic Problems on Domains with Rapidly Oscillating Boundaries

*Daniel Daners, Brigham Young University; and E. N. Dancer, University of Sydney, Australia*

#### 4:00-4:15 Continuation of Solutions to 1D and 2D Nonlinear Elliptic PDEs by the Multi-quadric Method

*A. Fedoseyev and M. Friedman, University of Alabama, Huntsville; and E. Kansa, Lawrence Livermore National Laboratory*

#### 4:20-4:35 On the Vibrations of a Plate-Beam Structure

*Marie Grobbelaar, University of Pretoria, South Africa*

#### 4:40-4:55 On the Multiplicity of Solutions of Two Nonlocal Variational Problems

*Xiaofeng Ren, Utah State University*

Tuesday, May 25

## Dinner

5:30 PM-7:00 PM

Attendees are on their own.



7:30 PM-9:30 PM  
Concurrent Sessions

Tuesday, May 25

## CP25

### Data Analysis II

7:30 PM-9:30 PM

*Room: Ballroom I*

*Chair: Ernest Barany, New Mexico State University, Las Cruces*

#### 7:30-7:45 Dynamical Aspects of System Identification

*Ernest Barany and Richard Colbaugh, New Mexico State University, Las Cruces*

#### 7:50-8:05 Interspike Interval Embedding Theorem

*Takashi Nishikawa and Celso Grebogi, University of Maryland, College Park; and Tim Sauer, George Mason University*

#### 8:10-8:25 Symbolic Sequence Approach to Biological Oscillator Dynamics

*Sarah Leshner, University of Maryland, College Park; Ulrike Feudel, Universität Potsdam, Germany; and Michal Zochowski, Yale University*

#### 8:30-8:45 Error Statistics, Model Selection and Confidence in Chaotic Time-Series Prediction

*Joshua T. Wood and Erik M. Bollt, U. S. Naval Academy*

#### 8:50-9:05 An Application of Computational Topology to Dynamical Systems

*Vanessa Robins, James D. Meiss, and Elizabeth Bradley, University of Colorado, Boulder*

#### 9:10-9:25 Sunspot Cycle: A Driven Nonlinear Oscillator?

*Milan Palus, Institute of Computer Science AS CR, Praha, Czech Republic; and Dagmar Novotna, Institute of Atmospheric Physics, AS CR, Praha, Czech Republic*

Tuesday, May 25

## **CP26**

### **Mathematical Biology II**

**7:30 PM-8:50 PM**

*Room: Ballroom II*

*Chair: Jonathan E. Rubin, The Ohio State University*

**7:30-7:45 Geometric Analysis of Population Rhythms in Neuronal Network Models with Fast Inhibitory Synapses**

*Jonathan E. Rubin and David Terman, The Ohio State University*

**7:50-8:05 The Viscous Nonlinear Dynamics of Twist and Writhe**

*Raymond E. Goldstein, University of Arizona; Thomas R. Powers, Harvard University; and Chris H. Wiggins, Courant Institute of Mathematical Sciences, New York University*

**8:10-8:25 Adaptive Mesh Refinement for Simulating Excitable Media**

*Elizabeth M. Cherry, Henry S. Greenside, and Craig S. Henriquez, Duke University*

**8:30-8:45 Chaos and Self-Organization in the Three-Letter Code Heteropolymer Model**

*Jose M. Zaldivar and Ariel Abecasis, European Commission Joint Research Center, Ispra, Italy*

Tuesday, May 25

## **CP27**

### **Coupled Oscillators II**

**7:30 PM-9:30 PM**

*Room: Ballroom III*

*Chair: M. K. Stephen Yeung, Cornell University*

**7:30-7:45 Time Delay in the Kuramoto Model of Coupled Oscillators**

*M. K. Stephen Yeung and Steven H. Strogatz, Cornell University*

**7:50-8:05 Dynamics of Continuous-Time Boolean Networks and Parkinsonian Tremor**

*Roderick Edwards, University of Victoria, Canada*

**8:10-8:25 Instabilities and Discrete Rotating Waves in Coupled Chaotic Oscillators**

*Manuel A. Matias and Esteban Sanchez, Universidad de Salamanca, España*

**8:30-8:45 Spatiotemporal Organization in Long Chains of Chaotic Oscillators with Impurities**

*Athanassios Gavrielides and Vassilios Kovanis, Air Force Research Laboratory, and Tsampikos Kottos, The Weizmann Institute of Sciences, Rehovot, Israel; and George Tsironis, University of Crete, Greece*

**8:50-9:05 Bifurcation Analysis of Spontaneous Symmetry-Breaking in Circular Josephson Junction Arrays**

*John J. Derwent and Mary Silber, Northwestern University*

**9:10-9:25 Synchronization in Arrays of Oscillators with Different Natural Frequencies**

*Leonid L. Rubchinsky and Mikhail M. Sushchik, Russian Academy of Sciences, Russia; and Grigory V. Osipov, Nizhny Novgorod State University, Russia*

Tuesday, May 25

## **CP28**

### **Patterns II/Oscillator II**

**7:30 PM-9:30 PM**

*Room: Magpie A/B*

*Chair: Mary Silber, Northwestern University*

**7:30-7:45 Parametrically Excited Surface Waves: Normal Form Symmetries and Pattern Selection**

*Mary Silber and Chad M. Topaz, Northwestern University; and Anne C. Skeldon, City University, Northampton Square, London, United Kingdom*

**7:50-8:05 Oscillatory Patterns in a Model of Autocatalytic Surface Reaction**

*Susanne Kömker, Universität Heidelberg, Germany*

**8:10-8:25 Multi-Phase Patterns in Periodically Forced Oscillatory Systems**

*Aric Hagberg, Los Alamos National Laboratory; Ehud Meron, Ben-Gurion University, Israel; and Christian Elphick, Centro de Fisica No Lineal y Sistemas Complejos de Santiago, Chile*

**8:30-8:45 Localized Traveling Waves Under the Influence of Temporal Modulation: Growing Worms and Pulses**

*Catherine Crawford and Hermann Riecke, Northwestern University*

**8:50-9:05 D<sub>4</sub> Equivariant Maps and the Takens-Bogdanov Bifurcation**

*A. M. Rucklidge, University of Cambridge, United Kingdom*

**9:10-9:25 Travelling Front Solutions Arising in a Chemotaxis-Growth Model**

*Tohru Tsujikawa, Miyazaki University, Japan*

Tuesday, May 25

## **CP29**

### **Control II**

**7:30 PM-9:30 PM**

*Room: Wasatch A/B*

*Chair: Marina Osipchuk, University of Minnesota, Minneapolis*

**7:30-7:45 Finite-Dimensional Control of a Nonlinear Distributed Parameter System**

*Marina Osipchuk, University of Minnesota, Minneapolis; Stas Y. Shvartsman and Yannis G. Kevrekidis, Princeton University; and Edriss S. Titi, University of California, Irvine*

**7:50-8:05 Control and Tracking in the Diamagnetic Kepler Problem**

*Babak Pourbohloul and Louis J. Dube, Université Laval, Québec, Canada*

**8:10-8:25 Feedback Linearization of Unstable Rolling Phenomenon**

*Bill Goodwine, University of Notre Dame; and Gábor Stépán, Technical University of Budapest, Hungary*

**8:30-8:45 Control of Distributed Autonomous Robotic Systems with Underlying Task Assignment**

*Peter Molnar, Clark Atlanta University; and Jens Starke, University of Heidelberg, Germany*

**8:50-9:05 Dynamic Model Reduction**

*David Kan, University of California, Los Angeles*

**9:10-9:25 Swimming Dynamics of a Shape-Changing Object**

*Hsi-Shang Li and I-Ming Chen, Nanyang Technological University, Singapore*

Tuesday, May 25

## **CP30**

### **Chaotic Maps II**

**7:30 PM-9:30 PM**

*Room: Golden Cliff*

*Chair: Tomasz Kapitaniak, University of Maryland, College Park; and Technical University of Łódź, Poland*

**7:30-7:45 Metamorphosis of Chaotic Saddle**

*Tomasz Kapitaniak, University of Maryland, College Park; and Technical University of Łódź, Poland; Ying-Cheng Lai, University of Maryland, College Park and University of Kansas, Lawrence; and Celso Grebogi, University of Maryland, College Park*

**7:50-8:05 The Breakdown of Shadowing in a Typical Physical System**

*Mitrajit Dutta, Edward Ott, and James A. Yorke, University of Maryland, College Park; and Ernest Barreto, George Mason University*

**8:10-8:25 Box Dynamics**

*Linda Moniz and James A. Yorke, University of Maryland, College Park*

**8:30-8:45 High-Quality Numerical Shadowing for Differential Equations**

*David E. Sigeti, John E. Pearson, and Scott M. Zoldi, Los Alamos National Laboratory*

**8:50-9:05 Spurious Lyapunov Exponents Computed Using the Eckmann-Ruelle Procedure**

*Joshua A. Tempkin, University of Maryland, College Park*

**9:10-9:25 Transition To High-Dimensional Chaos**

*Mary Ann Harrison and Ying-Cheng Lai, University of Kansas*

Tuesday, May 25

## **CP31**

### **Solitons II**

**7:30 PM-9:30 PM**

*Room: Maybird*

*Chair: Kim Rasmussen, Los Alamos National Laboratory*

**7:30-7:45 Large Discrete Breather Dynamics in the Presence of a Phonon Bath**

*Kim Rasmussen, Los Alamos National Laboratory*

**7:50-8:05 Radiation Loss of Dispersion-Managed Solitons in Optical Fibers**

*Tian-Shiang Yang and William L. Kath, Northwestern University*

**8:10-8:25 Solitonic Excitations on Lattice Systems**

*Panayotis Kevrekidis, Rutgers University*

**8:30-8:45 Global Boundary Stabilization of the Korteweg-de Vries-Burgers' Equation**

*Wei-Jiu Liu and Miroslav Krstic, University of California, San Diego*

**8:50-9:05 Periodic Solutions of Nonlinear Schrödinger Equation In the Strong Dispersion Management Regime**

*Vadim Zharnitsky, Brown University*

**9:10-9:25 Approximate Group Theoretic Laws for Self-focusing and Solitons**

*D. Subbarao and R. Uma, Indian Institute of Technology, Delhi, India*

Tuesday, May 25

## **CP32**

### **Numerics II**

**7:30 PM-9:30 PM**

*Room: Superior A*

*Chair: Kurt Lust, Cornell University*

**7:30-7:45 Robust Newton-Picard Methods for Bifurcation Analysis of Periodic Solutions of Partial Differential Equations**

Kurt Lust, Cornell University

**7:50-8:05 The Effects of Collocation Methods on Local Bifurcations of Flows**

E. A. D. Foster, Memorial University of Newfoundland, Canada

**8:10-8:25 Unconditionally Gradient Stable Time Marching the Cahn-Hilliard Equation**

David J. Eyre, University of Utah

**8:30-8:45 Finite Difference Approximations of Delay Differential Control Systems**

Boris Mordukhovich and Ruth Trubnik, Morris Brown College

**8:50-9:05 Numerical Computation of Solitons and Waves Using Adaptive Moving Grids**

P. A. Zegeling, Utrecht University, The Netherlands

**9:10-9:25 A Dynamical System Associated with Newton's Method for Parametric Approximations of Convex Minimization Problems**

José Manuel Pérez Cerdá Penablanca, Villa Alemana, Chile

Tuesday, May 25

## **CP33**

### **Transport II**

**7:30 PM-8:50 PM**

*Room: Superior B*

*Chair: Harry Dankowicz, Royal Institute of Technology, Stockholm, Sweden*

**7:30-7:45 Slow Diffusion and Effective Stability of Dust Particles Orbiting Asteroids**

Harry Dankowicz, Royal Institute of Technology, Stockholm, Sweden

**7:50-8:05 Turbulent Transport by Waves**

Alexander M. Balk, University of Utah

**8:10-8:25 Power Spectrum of Passive Scalars in Two Dimensional Chaotic Flows**

Guo-Cheng Yuan, Thomas M Antonsen, Jr., Edward Ott, and Keeyeon Nam, University of Maryland, College Park

**8:30-8:45 Lagrangian Diffusion in Chaotic Fluid Flows**

Fabio H. Palladino, Iberê L. Caldas and Gilberto Corso, Universidade de São Paulo, Brasil

Tuesday, May 25

## **CP34**

### **Partial Differential Equations II**

**7:30 PM-9:30 PM**

*Room: White Pine*

*Chair: Renate Schaaf, Utah State University*

**7:30-7:45 Title to be determined**

Renate Schaaf, Utah State University

**7:50-8:05 Structural Analysis of Incompressible Flows**

Shouhong Wang, Indiana University, Bloomington

**8:10-8:25 Slow Manifolds and Inertial Manifolds in the Maxwell-Bloch Equations**

Govind Menon and Gyorgy Haller, Brown University

**8:30-8:45 Optimal Gap Conditions for Invariant Manifolds**

Y. Latushkin and William Layton, University of Missouri, Columbia

**8:50-9:05 Mean Curvature Laws for Spreading Solid Films**

Kirk Brattkus, Southern Methodist University

**9:10-9:25 On the Stabilization of Bounded Solutions for Parabolic Systems with Analytic Nonlinearity and Lyapunov Functional**

Mikhail Vishnevskii, Russian Academy of Science, Siberian Branch; and Universidade Federal do Para, Guama, Para, Brasil

## Wednesday, May 26

For papers with multiple authors,  
*the speaker is shown in italics*,  
 if known at press time.

Wednesday, May 26

### Registration Open

7:30 AM-4:00 PM

*Location: Ballroom Lobby*

Wednesday, May 26

### IP7

#### Application of Dynamical Systems Theory to Spacecraft Trajectory Design Including GENESIS

8:30 AM-9:30 AM

*Room: Ballrooms I, II & III*

*Chair: James Yorke, University of Maryland, College Park*

Accomplishment of many short- and long-term science and exploration goals will require innovative spacecraft trajectory concepts and efficient design tools for analysis and implementation. For example, a number of space missions have recently been proposed that aim to take advantage of the growing scientific interest in the region of space near libration points in the Sun-Earth/Moon system. Baseline concepts for such missions are founded on solutions to the three- and four-body problems. Since no such general solutions exist, new philosophies for design must be

considered; a more complete understanding of the solution space is imperative. At the same time, recent evidence supports the theory that the rich dynamics in this region of space may lead to previously undiscovered solutions. Thus, there is a current focus on obtaining a clearer understanding of the fundamental dynamics associated with the trajectory design problem, particularly in multi-body regimes, where qualitative information is needed concerning sets of solutions and their evolution. Nonlinear dynamical systems theory is a key component in progress toward that objective. The newly selected Discovery class GENESIS mission provides an opportunity to demonstrate the usefulness of dynamical systems theory in initiating trajectory design. Invariant manifolds have served as a guide to generate natural pathways and establish trajectory options near the libration points. A longer term goal in this program is to knowledgeably select and compute trajectory arcs in the multi-body problem. Such capability will support not only trajectory design, but also guidance and control, and provide a basis for evaluation of low-thrust applications in this region of space.

**Kathleen C. Howell**

*Department of Aeronautics and Astronautics  
 Purdue University, West Lafayette*

Wednesday, May 26

### Coffee

9:30 AM-10:00 AM

*Location: Ballroom Lobby*



10:00 AM-12:00 PM  
 Concurrent Sessions

Wednesday, May 26

### MS36

#### Topological Entropy and Average Expansion Rates: Communication, Synchrony, and Dimension

10:00 AM-12:00 PM

*Room: Ballroom I*

Recent work on communicating with chaos has led to renewed interest in calculating topological entropy. The speakers will describe how reducing error rates in chaos communication schemes limits the allowed symbol sequences and thus decreases the topological entropy of the system, new numerical methods for calculating topological entropy in terms of average expansion rates, the identification of new desynchronization bifurcations in coupled chaotic systems using these methods, and discuss methods based on average expansion rates which permit efficient calculation of capacity dimension.

**Organizers: Ernest Barreto and**

**Paul So**

*George Mason University*

#### 10:00-10:25 Dynamics of Coding in Communicating with Chaos

*Erik M. Bollt, U. S. Naval Academy;  
 and Ying-Cheng Lai, University of Kansas*

#### 10:30-10:55 Calculating Topological Entropy with an Application to Communicating with Chaos

*Joeri Jacobs, Edward Ott, and Brian R. Hunt,  
 University of Maryland, College Park*

#### 11:00-11:25 From Generalized Synchrony to Topological Decoherence: The Decoherence Bifurcation

*Ernest Barreto and Paul So, Organizers*

#### 11:30-11:55 Box-counting Dimension Without Boxes: Calculating $D_0$ from Average Expansion Rates

*Paul So and Ernest Barreto, Organizers;  
 and Brian R. Hunt, University of Maryland, College Park*

Wednesday, May 26

## MS37

### Geometric Approximation Methods in Ocean Modeling

10:00 AM-12:00 PM

*Room: Ballroom II*

One well-documented feature of global ocean circulation is its large variability in regions adjacent to coherent western-intensified currents such as the Kuroshio Current and the Gulf Stream. This variability limits predictability of mean properties such as the poleward heat transport, which in turn affects the accuracy in determining the Earth's climate in coupled ocean-atmosphere models. Current general circulation models (GCMs) typically underestimate this variability greatly when compared to available observations (e.g.: Topex/Poseidon). The physical origins of variability are doubtless complex in detail and include delicate potentially unstable feedback in the air-sea interaction. Variability in current GCMs may be constrained by inadequate parameterization and limited dynamical range which, at 25 km, (in global simulations) is at best marginal with respect to mesoscale physics. In this respect, the considerable recent interest among the oceanographic community in decadal and longer-period variability of the circulation only underscores the need to understand the underlying mathematical and geometrical structure in simulating complex systems such as ocean circulation and the air-sea interaction responsible for our climate. The speakers will discuss their individual approaches and recent progress in studying various dynamical systems aspects of this problem.

**Organizer:** Darryl D. Holm  
*Los Alamos National Laboratory*

#### 10:00-10:25 Extended Geostrophic Euler-Poincaré Ocean Models

J. S. Allen and P. A. Newberger, Oregon State University; and Darryl D. Holm, Organizer

#### 10:30-10:55 Successive Bifurcations In the Oceans' Wind-driven Circulation

Michael Ghil, University of California, Los Angeles

#### 11:00-11:25 Dynamical Systems Challenges in Assessing Ocean Transport

Christopher K. R. T. Jones, Brown University

#### 11:30-11:55 Material Dispersion in Wind-driven Ocean Gyre

James C. McWilliams and Pavel Berloff, University of California, Los Angeles

Wednesday, May 26

## MS38

### Analysis and Application of Piecewise Smooth Dynamical Systems and Their Bifurcations

10:00 AM-12:00 PM

*Room: Ballroom III*

The main theme of this minisymposium is the analysis of piecewise-smooth dynamical systems and their bifurcations. Specifically, it has been shown that the system dynamics undergo dramatic changes when, by varying the parameters, the system trajectory (or part of it) becomes tangent to one of the boundaries dividing the phase space into different regions associated with different (smooth) system configurations. This novel type of bifurcations, termed order-collision (Nusse & Yorke 1992) and grazing (Nordmark 1991), have been shown to organize the dynamical behavior of several systems of relevance in applications such as power electronic converters, vibro-impacting mechanical devices, and friction oscillators. The speakers will discuss their latest results in this area and present some examples of relevance in applications.

**Organizer:** Mario di Bernardo  
*University of Bristol, United Kingdom*

#### 10:00-10:25 Nonsmooth Bifurcations, Sliding Orbits and Their Application in Piecewise Smooth Dynamical Systems

Mario di Bernardo, Organizer; and Chris J. Budd, University of Bath, United Kingdom

#### 10:30-10:55 Describing the Bifurcations of Piecewise Smooth Systems

James A. Yorke, University of Maryland, College Park; and Helena E. Nusse, University of Groningen, The Netherlands

#### 11:00-11:25 Graph Theory, Probability and Many Dimensional Piecewise Smooth Dynamical Systems

Martin E. Homer and S. J. Hogan, University of Bristol, United Kingdom

#### 11:30-11:55 Analysis of Grazing Bifurcations in a Continuous and Piecewise Differentiable Friction Model

Arne B. Nordmark and Harry Dankowicz, Royal Institute of Technology, Stockholm, Sweden

Wednesday, May 26

## MS39

### Dynamics and Structures with Fractal Spectra

10:00 AM-12:00 PM

*Room: Magpie A/B*

Usually accepted distinction between order (periodicity or quasiperiodicity) and chaos is not complete: there are processes between order and chaos, and they are often characterized with fractal (singular continuous) power spectra. Recent studies have shown abundance of the dynamics with fractal spectra in Hamiltonian and dissipative nonlinear systems. Similar properties have been also found in solid states (quasicrystals) and in quantum chaos. This minisymposium is focused on the mechanisms of appearance of fractal spectra, the methods of their characterization, and implications for transport properties in quantum systems and solids.

**Organizer:** Arkady Pikovsky  
*Universität Potsdam, Germany*

#### 10:00-10:25 Dynamics with Singular Continuous Spectra: Mechanisms and Renormalization Group

Description  
Arkady Pikovsky, Organizer

#### 10:30-10:55 Multifractal Spectra and Eigenfunction: What Determines the (Anomalous) Spreading of Wave Packets?

T. Geisel, Max-Planck-Institut für Stromungsforschung and Universität Göttingen, Germany; R. Ketzmerick, Universität Göttingen, Germany; and K. Kruse, Max-Planck Institut für Stromungsforschung

#### 11:00-11:25 Hidden Dimer in Frenkel-Kontorova Model: Extended, Critical and Localized States in Quasiperiodic System with an Infinite Number of Steps

Indu Satija, George Mason University; and Jukka Ketoja, KCL Paper Science Center, Espoo, Finland

#### 11:30-11:55 Dissipative and Hamiltonian Dynamics with Fractal Fourier Spectra: Symbolic Description and Multifractality

Michael Zaks and Jürgen Kurths, Universität Potsdam, Germany

**Wednesday, May 26**

## **MS40**

### **Space Missions and Dynamical Systems**

**10:00 AM-12:00 PM**

*Room: Wasatch A/B*

Modern dynamical systems theory began with Poincaré's study of the three-body problem. Space missions are increasingly more complex; demands on the orbit to solve engineering problems have grown beyond the conic-centered astrodynamical infrastructure. The delicate heteroclinic dynamics used by the Genesis Mission dramatically illustrates the need for a new paradigm: dynamical systems. Furthermore, the same dynamics has much more to say about the morphology and transport of material within the Solar System. The synergistic interplay between the natural dynamics of the Solar System and applications to engineering is a guiding principle in this field.

**Organizer:** Martin W. Lo

*Jet Propulsion Laboratory, California Institute of Technology*

**10:00-10:25 From Genesis to Armageddon**

Martin W. Lo, Organizer

**10:30-10:55 Heteroclinic Connections and Resonance Transitions in Celestial Mechanics**

Wang Sang Koon, California Institute of Technology

**11:00-11:25 Tools to Explore Libration Point Orbits**

Gerard Gomez, Universitat de Barcelona, España; and J. Masdemont, Universitat Politècnica de Catalunya, España

**11:30-11:55 Libration Orbit Missions: Historical Perspective and Future Applications**

David Folta, Goddard Space Flight Center, Greenbelt, Maryland

**Wednesday, May 26**

## **MS41**

### **Dynamics of Scheduling Problems**

**10:00 AM-12:00 PM**

*Room: Golden Cliff*

This minisymposium deals with the dynamics of scheduling and queueing problems—e.g.: queueing networks in computer science or scheduling in re-entrant manufacturing systems. Recently, the methods of dynamical systems theory have been applied to these problems which traditionally have been discussed in terms of queueing theory. The dynamics of these problems are at times chaotic; in other cases, can be related to interval exchange maps. Attempts to use control of chaos ideas to optimize have also been made. The speakers will evaluate the dynamical systems methods in this context and discuss their relevance to realistic problems.

**Organizers:** Ivonne Diaz-Rivera

*AT&T Research*

**Dieter Armbruster**

*Arizona State University*

**10:00-10:25 Stability of Queueing and Fluid Reentrant Networks**

*John Hasenbein, University of Texas, Austin; Jim Dai and John Vande Vate, Georgia Institute of Technology*

**10:30-10:55 On the Optimal Scheduling for Warehouses**

*Leonid A. Bunimovich, Georgia Institute of Technology*

**11:00-11:25 A Dynamical Systems Analysis of a Periodic Client-Server Network**

*James A. Walsh, Oberlin College; B. Elenbogen, University of Michigan, Dearborn; and G. R. Hall, Boston University*

**11:30-11:55 Periodic Orbits in Re-Entrant Manufacturing Systems**

*Dieter Armbruster and Ivonne Diaz-Rivera, Organizers; and Tom Taylor, Arizona State University*

**Wednesday, May 26**

## **MS42**

### **The Continuous Spectrum and Its Implications for Pattern Formation**

**10:00 AM-12:00 PM**

*Room: Maybird*

This minisymposium focuses on the role of the continuous spectrum for pattern formation in nonlinear partial differential equations on unbounded domains. The effects of the continuous spectrum are relevant to dynamical behavior near shocks, spiral waves and various travelling waves. The continuous spectrum may cause bifurcations to other patterns in various ways. On one hand, discrete eigenvalues may pop out of the continuous spectrum and cross the imaginary axis, resulting in a bifurcation which can be described by a finite-dimensional dynamical system. On the other hand, the continuous spectrum itself may cross the imaginary axis, thus destabilizing the asymptotic states of the underlying wave. This phenomena can also lead to the creation of new stable spatio-temporal patterns. In contrast to the aforementioned mechanism, the dynamical system which describes this bifurcation is in general infinite-dimensional. The speakers will discuss recent progress in the analysis of these mechanisms and their consequences for the applications.

**Organizers:** Todd Kapitula

*University of New Mexico, Albuquerque*

**Björn Sandstede**

*Ohio State University, Columbus*

**10:00-10:25 Front Dynamics in a Spatially Discrete System**

*Neil J. Balmforth, University of California, Santa Cruz*

**10:30-10:55 Evans Function Analysis in the Continuous Spectrum and Applications**

*Robert Gardner, University of Massachusetts, Amherst*

**11:00-11:25 Essential Instability of Pulses, and Bifurcation to Modulated Travelling Waves**

*Björn Sandstede, Organizer; and Arnd Scheel, Freie Universität, Berlin, Germany*

**11:30-11:55 Existence and Stability of Dark Solitons**

*Todd Kapitula, Organizer; and Jonathan Rubin, Ohio State University*

Wednesday, May 26

## **MS43**

### **Calcium Dynamics: Oscillations, Sparks, and Waves**

**10:00 AM-12:00 PM**

*Room: Superior A*

No description was available when this program went to press.

**Organizer:** John E. Pearson  
*Los Alamos National Laboratory*

**10:00-10:25 The Spatial Distribution of IP<sub>3</sub> Receptors and the Dynamics of Intracellular Calcium**

Igor Mitkov and John E. Pearson, Los Alamos National Laboratory; and Silvina Ponce Dawson, Universidad de Buenos Aires, Argentina

**10:30-10:55 Calcium Dynamics in Astrocytes**

Joe Raquepas, University of Utah

**11:00-11:25 Elementary Events of Intracellular Calcium Signaling**

Ian Parker, University of California, Irvine

**11:30-11:55 Geometrical Analysis on the Intracellular Calcium Wave Propagation**

Young-seon Lee and James Keener, University of Utah

Wednesday, May 26

## **MS44**

### **Stochastic Stability of Dynamical Systems**

**10:00 AM-12:00 PM**

*Room: Superior B*

The behavior of dynamical systems under random perturbation is of vital importance in applications and modelling. Hyperbolic dynamical systems are one class in which the behavior under random perturbation is partially understood and this knowledge has proved useful in calculating dynamical invariants and invariant measures. This minisymposium will discuss such results and also address recent results for another class of important model systems: forced or skew product systems. These results concern the existence, regularity and stability properties of invariant graphs in forced systems, and are important in understanding the stability of chaotic synchronized systems to noise, and dimension increase in recursive filters. The intended audience includes workers in nonlinear signal processing and applied dynamical systems.

**Organizers:** Jaroslav Stark  
*University College London, United Kingdom*

**Matthew J. Nicol**  
*University of Manchester Institute of Science and Technology, Manchester, United Kingdom*

**10:00-10:25 Graphs and the Stability of Stochastically Forced Systems**

Jaroslav Stark, Organizer

**10:30-10:55 Approximation of Invariant Measures for Random Compositions of Maps**

Anders Oberg, Uppsala University, Sweden

**11:00-11:25 Stability of Attractors in Forced Systems**

Matthew J. Nicol, Organizer

**11:30-11:55 Attractors, Chain Transitive Sets and Invariant Measures**

Fern Hunt, National Institute of Standards and Technology, Gaithersburg

Wednesday, May 26

## **MS45**

### **Geometric Analysis in Hydrodynamics**

**10:00 AM-12:00 PM**

*Room: White Pine*

The geometric analysis of geodesic flow on the group of volume-preserving diffeomorphisms, SDiff, answers fundamental questions about the motion of an ideal fluid, such as questions of existence and stability of the solutions to the Euler equations. Recently, great progress has been made in a number of directions: it has been proven that any two fluid configurations can be connected by a generalized flow, the exponential map on SDiff(Tn) has been shown to be Fredholm, and new averaged Euler equations have been obtained as geodesics on SDiff with H1 (as opposed to L2) metric. This symposium will explore the connections between these new developments and their consequences for a better understanding of fluid motion.

**Organizer:** Steve Shkoller  
*Los Alamos National Laboratory*

**10:00-10:25 Geometry and Curvature of New Diffeomorphism Groups and the Averaged Euler Equations**

Steve Shkoller, Organizer

**10:30-10:55 The SU(n) Approximation to the 2D Averaged Euler Equations**

Sergey Pekarsky, California Institute of Technology

**11:00-11:25 A Nonlinear Analysis of the Averaged Euler Equations**

Jerrold E. Marsden, California Institute of Technology

**11:30-11:55 New Pressure Estimates for the 2D Euler Equation**

Peter Topping, Mathematical Sciences Research Institute

Wednesday, May 26

## **Lunch**

**12:00 PM-1:30 PM**

Attendees are on their own.



Wednesday, May 26

## IP8

### Quantitative Studies of the Fertilization Wave in Eggs

1:30 PM-2:30 PM

*Room: Ballrooms I, II & III*

*Chair: John Guckenheimer, Cornell University*

Propagating waves of calcium ions have been observed in a wide variety of living cells. These waves function as part of the second messenger role of calcium in transmitting signals from hormone receptors and other molecular detectors in the plasma membrane. In egg cells, calcium waves are initiated by the egg-sperm fusion event and have been observed in every species studied. After dormancy for many years, the fertilization calcium wave stimulates events that activate metabolism and development of the egg. The speaker will discuss a model of calcium handling in eggs from the African frog, *Xenopus laevis*, and describe simulations in two- and three-dimensions that help to understand the mechanisms of initiation, propagation and termination of the wave.

**Joel Keizer**

*Institute of Theoretical Dynamics,  
University of California, Davis*

Wednesday, May 26

## Coffee

2:30 PM-3:00 PM

*Location: Ballroom Lobby*



3:00 PM-5:00 PM  
Concurrent Sessions

Wednesday, May 26

## CP35

### Data Analysis III

3:00 PM-4:40 PM

*Room: Ballroom I*

*Chair: Boris Naujoks, Universität Dortmund, Germany*

#### 3:00-3:15 Nonlinear Dynamic Signal Processing of Chaotic Noise in a Real Channel

Kevin M. Short, University of New Hampshire

#### 3:20-3:35 Prediction and Noise Filtering in Dynamical Systems: A Neural Network Approach

Gustavo Deco, Siemens AG, Munich, Germany; and Louis J. Dube, Université Laval, Québec, Canada

#### 3:40-3:55 The AWARE (Advanced Warning Against Runaway Events) Project

Fernanda Strozzi, Libero Istituto Universitario Carlo Cattaneo, Castellanza, Italy; and Jose M. Zaldivar, European Commission Joint Research Center, Ispra, Italy

#### 4:00-4:15 Tracking Doppler-Shifted Chaotic Waveforms

Daniel W. Hahs and Ned J. Corron, Dynetics, Inc., Huntsville, Alabama

#### 4:20-4:35 Modeling of Large-Scale Complex Adaptive Systems

Radoslaw Zapert and Huanrui Hu, PricewaterhouseCoopers LLP

Wednesday, May 26

## CP36

### Synchronization

3:00 PM-5:00 PM

*Room: Ballroom II*

*Chair: Epaminondas Rosa, Jr., University of Miami*

#### 3:00-3:15 Transition to Phase Synchronization of Chaos

Epaminondas Rosa, Jr., University of Miami

#### 3:20-3:35 Synchronized Finger Tapping and 1/ $f^{\alpha}$ Type Long Memory Processes

Mingzhou Ding, Florida Atlantic University

#### 3:40-3:55 Weak Synchronization of Chaotic Coupled Map Lattices

Stefano Boccaletti, Universidad de Navarra, España

#### 4:00-4:15 Understanding Phase Synchronization in Terms of Periodic Orbits

Jürgen Kurths, Universität Potsdam, Germany

#### 4:20-4:35 Destruction of Resonances in Two-Mode Quasilinear Dynamical Systems

Yury A. Tsarin and Dmytro M. Vavrik, Institute of Radio Astronomy, Kharkov, Ukraine

#### 4:40-4:55 Laser Spectral Waves: from Pattern Formation to Spatiotemporal Chaos

Jerome Plumecoq, Christophe Szwaj, Dominique Derozier, Marc Lefranc and Serge Bielawski, Université des Sciences et Technologies de Lille, Villeneuve d'Ascq Cedex, France; and Thomas Erneux, Universiteit Libre de Bruxelles, Belgium

Wednesday, May 26

## CP37

### Pattern Formation in the Cahn-Hilliard Model — Part II of II

**3:00 PM-5:00 PM**

*Room: Ballroom III*

*Chair: Thomas Wanner, University of Maryland, Baltimore County*

For Part I, see MS33

In the forty years since its introduction, the Cahn-Hilliard model has proved its ability to exhibit pattern formation and phase separation phenomena like those being observed in binary metallic alloys. Therefore, understanding the dynamical behavior of the model is of immediate interest in materials sciences. While existing mathematical results for the one-dimensional model provide a fairly complete picture of its rich dynamics, most of the current research focuses on the physically more relevant two- and three-dimensional models, as well as their discrete and multi-component counterparts. The talks in the minisymposium will cover a broad spectrum of these recent studies.

#### 3:00-3:15 Existence of Connecting Orbits In Cahn-Hilliard

Konstantin Mischaikow, Georgia Institute of Technology

#### 3:20-3:35 Pattern Formation and Spatial Entropy in Spatially Discrete Cahn-Hilliard Equations

Erik S. Van Vleck, Colorado School of Mines

#### 3:40-3:55 Spinodal Decomposition for the Cahn-Hilliard Equation

Evelyn Sander, George Mason University; Stanislaus Maier-Paape, Georgia Institute of Technology; and Thomas Wanner, University of Maryland, Baltimore County

#### 4:00-4:15 Allen-Cahn/Cahn-Hilliard Systems with Degenerate Mobility

Amy Novick-Cohen, Technion-Israel Institute of Technology, Israel

#### 4:20-4:35 Pattern Evolution in the Discrete Cahn-Hilliard Equation

Christopher P. Grant, Brigham Young University

#### 4:40-4:55 Spinodal Decomposition for the Cahn-Hilliard-Cook Equation-Linear Theory

Dirk Blömker, Universität Augsburg, Germany

Wednesday, May 26

## CP38

### Nonlinear Waves

**3:00 PM-5:00 PM**

*Room: Magpie A/B*

*Chair: Edgar Knobloch, University of California, Berkeley*

#### 3:00-3:15 Dynamics of Counter-propagating Waves In Parametrically Forced Systems

Edgar Knobloch, University of California, Berkeley; Carlos Martel and Jose M. Vega, Universidad Politecnica de Madrid, España

#### 3:20-3:35 Linear Conversion of Parallel Waves

Allan N. Kaufman, Lawrence Berkeley National Laboratory and University of California, Berkeley; E. R. Tracy, College of William & Mary; James J. Morehead and Alain J. Brizard, Lawrence Berkeley National Laboratory

#### 3:40-3:55 Dynamics, Bifurcations, and Stability of Fronts in the Optical Parametric Oscillator

J. Nathan Kutz, University of Washington; T. Erneux, Universiteit Libre de Bruxelles, Belgium

#### 4:00-4:15 Fronts and Pulses in Reaction-Diffusion Equations and Their Stability

Geertje M. Hek, Utrecht University, The Netherlands

#### 4:20-4:35 Dynamics of Solitary Pulses in Isotropic and Anisotropic Reaction Diffusion Systems

J. Krishnan, Ioannis G. Kevrekidis, Princeton University; Koen Engelborghs and Dirk Roose, Catholique Universiteit Leuven, Belgium; and Markus Bar, Max-Planck Institut für Physik Komplexer Systeme, Dresden, Germany

#### 4:40-4:55 The Coupled, Weakly-Nonlinear Evolution of Two Counter-Rotating Waves and the Associated Streaming Flow in Finite Geometries

Maria Higuera, José A. Nicolas, and José M. Vega, Universidad Politecnica de Madrid, España

Wednesday, May 26

## CP39

### Applications II

**3:00 PM-5:00 PM**

*Room: Wasatch A/B*

*Chair: Louis Pecora, U. S. Naval Research Laboratory*

#### 3:00-3:15 Detecting Invariant Manifolds in Time Series: Biological Data

Louis Pecora, U. S. Naval Research Laboratory

#### 3:20-3:35 Weather Prediction and Residual Delay Maps: Isolating Regions of Atmospheric Nonlinearity to Compare Different Atmospheric Models

Dhananjay Patil, University of Maryland, College Park

#### 3:40-3:55 Nonlinear Techniques for Detecting Physical Forcing of Ecological Systems: A Working Example

Paul Dixon, University of California, San Diego

#### 4:00-4:15 Nonlinear and Nonequilibrium Phenomena in Cell Motility

Josef Kas, University of Texas, Austin

#### 4:20-4:35 Nonlocal Reaction-Diffusion Equations for Microwave Heating Applications

Amitabha Bose and Gregory Kriegsmann, New Jersey Institute of Technology

#### 4:40-4:55 Spatially Complex Localization In Twisted Constrained Elastic Rods

G. H. M. van der Heijden and J. M. T. Thompson, University College London, United Kingdom; and A. R. Champneys, University of Bristol, United Kingdom

Wednesday, May 26

## **CP40**

### **Applications III — Orbital Dynamics and Plasma Dynamics**

**3:00 PM-5:00 PM**

*Room: Golden Cliff*

*Chair: Robert L. Warnock, Stanford Linear Accelerator Center*

#### **Orbital Dynamics**

**3:00-3:15 Power Limited Optimal Rendezvous Between Spacecraft**  
*Yechiel Crispin and Virginie Guerre, Embry-Riddle University*

**3:20-3:35 Evolving Perturbed Hamiltonian Systems with Lie Transformations**

*Liam M. Healy, U. S. Naval Research Laboratory*

**3:40-3:55 An Optimal Control Problem for Satellite Dynamics via Wavelets**  
*Antonina Fedorova and Michael Zeitlin, Russian Academy of Sciences, St. Petersburg, Russia*

#### **Plasma Dynamics**

**4:00-4:15 Solutions of the Vlasov-Fokker-Planck Equation for Electrons in a Storage Ring**  
*Robert L. Warnock, Stanford Linear Accelerator Center*

**4:20-4:35 Experimental Observation of Chaos in a Plasma Discharge Tube**

*Jonathan A. Walkenstein, William B. Pardo, Torben N. Buch, Marco Monti, and Epaminondas Rosa, Jr., University of Miami*

**4:40-4:55 Dynamics of a Chaotic Magnetic Limiter In Tokamaks**  
*Kai Ullmann and Ibere L. Caldas, Universidade de São Paulo, Brasil*

Wednesday, May 26

## **CP41**

### **Forced Biosystems**

**3:00 PM-4:40 PM**

*Room: Maybird*

*Chair: Ulrike Feudel, Universität Potsdam, Germany*

**3:00-3:15 Complex Behavior in Quasiperiodically Forced Biological Oscillators**

*Ulrike Feudel, Universität Potsdam, Germany*

**3:20-3:35 Embedding and Reconstruction of Forced Systems**

*Jaroslav Stark, University College London, United Kingdom*

**3:40-3:55 Detecting Weak Interaction from Bivariate Data**

*Michail Rosenblum, J. Kurths, and C. Schaefer, Universität Potsdam, Germany; P. Tass, Heinrich-Heine Universität, Germany*

**4:00-4:15 Synchronization of Noisy Systems by Stochastic Signals**

*Alexander Neiman and Frank Moss, University of Missouri, St. Louis; Lutz Schimansky-Geir, Humboldt Universität, Germany; Boris Shulgen and James Collins, Boston University*

**4:20-4:35 Modelling Edge Detection Using A Network of Pulse-Coupled Neurons**

*Robert H. Clewley, University of Bristol, United Kingdom*

Wednesday, May 26

## **CP42**

### **Patterns III**

**3:00 PM-5:00 PM**

*Room: Superior A*

*Chair: Gemunu H. Gunaratne, University of Houston*

**3:00-3:15 An Analysis of Cellular Flame Patterns**

*Gemunu H. Gunaratne, University of Houston*

**3:20-3:35 Instabilities of Hexagonal Pattern in the Presence of Rotation**

*Blas Echebarria and Hermann Riecke, Northwestern University*

**3:40-3:55 Super-Patterns and Parameter Collapse in Reaction-Diffusion Systems**

*Stephen L. Judd and Mary Silber, Northwestern University*

**4:00-4:15 Cross-Newell Equations for Triangles and Hexagons**

*Rebecca B. Hoyle, University of Cambridge, United Kingdom*

**4:20-4:35 Multibump Patterns Near a Co-Dimension 2 Point**

*Vivi Rottschäfer, University of Utrecht, The Netherlands, and Boston University*

**4:40-4:55 Modal Decomposition of Hopping States In Cellular Flames**

*Antonio Palacios, Michael Gorman, and Gemunu Gunaratne, University of Houston*

Wednesday, May 26

## CP43

### Vortex Dynamics

3:00 PM-5:00 PM

*Room: Superior B*

*Chair: Monika Nitsche, University of New Mexico, Albuquerque*

#### 3:00-3:15 Chaotic Dynamics In Vortex Cores

*Monika Nitsche, University of New Mexico, Albuquerque; and Robert Krasny, University of Michigan, Ann Arbor*

#### 3:20-3:35 Instabilities of Vortex Filaments in Oscillatory Media

*Guillaume Rousseau and Hugues Chate, CEA, Centre d'Etudes de Saclay, Gif-sur-Yvette, France; and Raymond Kapral, University of Toronto, Canada*

#### 3:40-3:55 Tracer Dynamics in a Flow of Driven Vortices

*Fred Feudel and Annette Witt, Universität Potsdam, Germany; and Celso Grebogi, University of Maryland, College Park*

#### 4:00-4:15 Topological Bifurcations in the Vortex Breakdown

*Morten Brøns, Lars K. Voigt and Jens N. Sørensen, Technical University of Denmark, Lyngby, Denmark*

#### 4:20-4:35 Five Point Vortices Which Exhibit Relaxation Oscillation

*Tatsuyuki Nakaki, Hiroshima University, Japan*

Wednesday, May 26

## CP44

### Polymers

3:00 PM-5:00 PM

*Room: White Pine*

*Chair: Qi Wang, Indiana University, Purdue University*

#### 3:00-3:15 Capillary Instability in Free Surface Jets of Liquid Crystal Polymers

*Qi Wang, Indiana University, Purdue University*

#### 3:20-3:35 Numerical Simulations of Complex Flows of LCPs Based on the Doi Theory

*Jimmy Feng, Levich Institute, City University of New York*

#### 3:40-3:55 Stress Selection and Phase Separation in the Doi Model for Solutions of Liquid Crystalline Polymers

*Peter D. Olmsted, University of Leeds, United Kingdom*

#### 4:00-4:15 Nonisothermal Spinning of Lyotropic and Thermotropic Liquid Crystalline Polymers

*Hong Zhou, University of North Carolina, Chapel Hill*

#### 4:20-4:35 A Continuum-Mechanical Theory for Nematic Elastomers

*Eliot Fried, University of Illinois, Urbana-Champaign*

Wednesday, May 26

## Dinner

5:00 PM-7:00 PM

Attendees are on their own.



Wednesday, May 26

## Poster Set-up

Poster boards will be available for presenters in Ballroom I, II, and III. Set-up is to be finished by 7:30 PM.

6:30 PM-7:30 PM

*Room: Ballroom I, II & III*

Wednesday, May 26

## Poster Session and Dessert Reception



7:30 PM-9:30 PM

*Room: Ballroom I, II & III*

### Distributions of Rotation Numbers

*Todd Ray Young, Ohio University, and IPST, University of Maryland, College Park*

### Controlling Transient Chaos in Deterministic Flows with Applications to Electrical Power Systems and Ecology

*Mukeshwar Dhamala and Ying-Cheng Lai, University of Kansas*

### A Study of a Forced Oscillator in an Electric Power System

*Alona Ben-Tal and Vivien Kirk, The University of Auckland, New Zealand*

### Markovian Analogue to Phase Transitions in Coupled Chaotic Map Lattices

*Francisco Sastre and Gabriel Perez, CINVESTAV-IPN, Unidad Merida, México*

### 1:2 Resonance Mediated Transmission Band Gap Opening in a 1-d Nonlinear Discrete Periodic Medium

*Anna V. Georgieva, Chemical Industry Institute of Toxicology; Thomas Kricherbauer, Universität München, Germany; and Stephanos Venakides, Duke University*

**Correlation of Inhaled Formaldehyde Flux Predictions with Regional DNA-Protein Crosslink Measurements in Rat Nasal Passages**

*Anna V. Georgieva, Paul Schlosser and Julia Kimbell, Chemical Industry Institute of Toxicology*

**Dynamical Systems as Kolmogorov Data Compressors**

*Todd K. Moon, Utah State University*

**Matched Asymptotic Expansions and Smolder Combustion**

*Daniel A. Schult, Colgate University*

**Cumulative Wavelength as a Source of Dynamical Information of the Molecular Gas Spectra**

*Vladimir P. Solov'ev and Brent W. Webb, Brigham Young University*

**A Mathematical Model of True Polar Wander**

*Melvin B. Leok and Jerrold E. Marsden, California Institute of Technology*

**Melnikov's Method, Bifurcations of Codimension One and Two and Exponentially Small Splittings of Separatrices in Forced Oscillators**

*Kazuyuki Yagasaki, Gifu University, Japan*

**Chaotic Transitions and Low-Frequency Fluctuations in Semiconductor Lasers with Delayed Optical Feedback**

*Ruslan L. Davidchack and Ying-Cheng Lai, University of Kansas, Lawrence; Athanasios Gavrielides and Vassilios Kovanis, Air Force Research Laboratory DELO*

**Dynamics of the Four-Level Laser with Injected Signal**

*Peter A. Braza, University of North Florida; and Carlos L. Pando, Universidad Autonoma de Puebla, México*

**Random and Deterministic Perturbation of a Class of Skew-Product Systems**

*Demetris Hadjiloucas, David Broomhead, and Matthew Nicol, UMIST, Manchester, United Kingdom*

**Unstable Periodic Orbits of Area Preserving Mappings**

*Babak Pourbohloul and Louis J. Dubé, Université Laval, Québec, Canada*

**Mode Interactions of Globally-Coupled Phase Oscillators**

*John David Crawford and Eric J. Hildebrand, University of Pittsburgh*

**A Generalized Single Wave Model for Unstable Electrostatic Waves**

*Anandhan Jayaraman and John David Crawford, University of Pittsburgh*

**Microextensive Chaos of a Spatially Extended System**

*Shigeyuki Tajima and Henry S. Greenside, Duke University*

**Resonant Pattern Formation in a Reaction-Diffusion PDE System**

*Alexandre Ardelea, Anna L. Lin and Harry L. Swinney, University of Texas, Austin*

**Possible Existence of Stochastic Resonances in Electrotelluric Time Series**

*Alejandro Ramírez-Rojas, Carlos G. Pavia-Miller, and Francisco Cervantes-De la Torre, Universidad Autónoma Metropolitana Azcapotzalco, México; and Fernando Angulo-Brown, Escuela Superior de Física y Matemáticas, IPN, México*

**Symbolic Analysis of Non-Stationary Time Series**

*E. R. Tracy, College of William and Mary; and Dennis M. Weaver, Saint Leo College*

**Libration Point Invariant Manifolds and Solar System Dynamics**

*Shane D. Ross, California Institute of Technology; and Martin W. Lo, Jet Propulsion Laboratory*

**Models for Insect Locomotion I: Dynamics and Stability in the Horizontal Plane**

*John Schmitt and Philip Holmes, Princeton University*

**Karhunen-Loeve Decomposition of Peripheral Blood Flow**

*Mario Hozic and Aneta Stefanovska, University of Ljubljana, Slovenia*

**Modeling and Controlling Molecular Dynamics**

*Sonja G. Schirmer, John V. Leahy, and Marvin D. Girardeau, University of Oregon*

**Symmetry Breaking of Eddies in Expanding Flows**

*Shinya Watanabe, Ibaraki University, Mito, Japan*

**Boundary Effects on Complex Ginzburg-Landau Dynamics**

*Victor M. Eguiluz, Emilio Hernandez-Garcia, and Oreste Piro, Campus Universitat de les Illes Balears, Palma de Mallorca, España*

**Defect Dynamics in the Vector Complex Ginzburg-Landau Equation**

*Emilio Hernandez-Garcia, Pere Colet, and Maxi San Miguel, Campus Universitat de les Illes Balears, Palma de Mallorca, España; and Miguel Hoyuelos, Universidad Nacional del Mar del Plata, Argentina*

**A Fractal Analysis of Electrotelluric Time Series**

*Francisco Cervantes-De la Torre, Alejandro Ramírez-Rojas and Carlos G. Pavia-Miller, UAM-AZCAPOTZALCO, México; and Fernando Angulo-Brown, Instituto Politécnico Nacional, México*

**Color Map of Lyapunov Exponents of Invariant Sets**

*Marco Monti, William B. Pardo, Jonathan A. Walkenstein, and Epaminondas Rosa, Jr., University of Miami; and Celso Grebogi, University of Maryland, College Park*

**Transition to High-Dimensional**

**Chaos in Coupled Oscillators**

*Lonnie Sauter and Ying-Cheng Lai,  
University of Kansas, Lawrence*

**The Multisymplectic Geometry and  
Variational Integrators for the  
Camassa-Holm Equation**

*Shinar O. Kouranbaeva, University of  
California Santa Cruz; and Steve Shkoller,  
Los Alamos National Laboratory*

**Synchronization and Communication  
Using Chaotic Frequency Modulation**

*A. R. Volkovskii and L. S. Tsimring,  
University of California, San Diego*

**Nonlinear Behavior of the Inner Ear**

*David E. Lerner and Darius Amani-Taleshi,  
University of Kansas, Lawrence; and  
Mark Chertoff, University of Kansas  
Medical Center*

**Identification of Decision Systems**

*R. Colbaugh, K. Glass, and E. Barany,  
New Mexico State University*

**Identification of Hybrid Dynamical  
Systems II: Case Studies**

*K. Glass, R. Colbaugh, T. S. Melker, and  
E. Barany, New Mexico State University*

**Identification of Hybrid Dynamical  
Systems I: Theory**

*R. Colbaugh, K. Glass, and E. Barany,  
New Mexico State University*

**Unstable Periodic Orbits and the  
Natural Measure of Nonattracting  
Chaotic Saddles**

*Mukeshwar Dhamala and Ying-Cheng Lai,  
University of Kansas*

**A Geometric Method for Calculating  
Diffusive Traveling Waves in Coupled  
Systems**

*David J. Eyre, University of Utah*

**Forecasting High Waters at Venice  
Lagoon using Chaos Theory  
Techniques**

*Jose M. Zaldivar, European Commission  
Joint Research Center, Ispra, Italy; Fernanda  
Strozzi, Libero Istituto Universitario Carlo  
Cattaneo, Castellanza, Italy; Eugenio  
Gutierrez, European Commission Joint  
Research Center, Ispra, Italy; and Alberto  
Tomasin, Universita Venice, Italy*

**Optimal Targeting of Chaos**

*Erik M. Bollt, U. S. Naval Academy; and  
Eric J. Kostelich, Arizona State University*

**On the Inverse Frobenius-Perron  
Problem (IFPP): Global Stabilization  
of Arbitrary Invariant Measures**

*Erik M. Bollt, U. S. Naval Academy*

**A Novel Measure of Nonstationarity  
in Dynamical Systems**

*Louis J. Dube and Frederic Beaulieu,  
Université Laval, Québec, Canada; and  
Gustavo Deco, Siemens AG, Munich,  
Germany*

**Extraction of Teleseismic Signal  
Waveforms from Background  
Noise Using Nonlinear Dynamic  
Forecasting**

*Kevin M. Short, University of New  
Hampshire*

**Filling the Rotation Interval at  
Discontinuous Bifurcations:  
A Continued Fraction**

*Carl Robert, University of Maryland,  
College Park; Kathleen T. Alligood and  
Tim Sauer, George Mason University*

**Critical Exponents for Higher  
Dimensional Crises**

*Carl Robert, Celso Grebogi, Edward Ott,  
and James A. Yorke, University of  
Maryland, College Park*

**Extracting Signals from Chaotic  
Laser Data**

*John B. Geddes and Kevin M. Short,  
University of New Hampshire*

**Average Expansion Rates and  
Dimension of Strange Nonchaotic  
Attractors**

*Paul So and Ernest Barreto, George Mason  
University; and Ulrike Feudel, Universität  
Potsdam, Germany*

**From High Dimensional Chaos to  
Stable Periodic Orbits: The Structure  
of Parameter Space**

*Murilo S. Baptista, Ernest Barreto, Celso  
Grebogi, University of Maryland, College  
Park*

**The Destruction of Horseshoes in 2D  
and 4D Symplectic Maps**

*David G. Sterling, Holger Dullin, James  
D. Meiss, University of Colorado, Boulder*

**Binary Fluid Convection as a 2x2  
Matrix Problem**

*Laurette Tuckerman, LIMSI-CNRS,  
Orsay, France*

**Oscillatory Neurocomputers With  
Dynamic Connectivity**

*Eugene M. Izhikevich, Arizona State  
University*

**Pulse Dynamics in Isotropic and  
Anisotropic Reaction-Diffusion  
Systems**

*J. Krishnan and Ioannis G. Kevrekidis,  
Princeton University; Koen Engelborghs,  
Dirk Roose and Markus Baer, Catholique  
Universiteit Leuven, Belgium; and  
Max-Planck Institut für Physik komplexer  
Systeme, Dresden, Germany*

**Subsystem Recurrences in High-  
dimensional Chaotic Systems**

*Scott M. Zoldi, Los Alamos National  
Laboratory*

**Big Islands in Dispersing Billiard-like  
Potentials**

*Vered Rom-Kedar, Courant Institute of  
Mathematical Sciences, New York University;  
and Dmitry Turaev, Weierstrass Institute  
for Applied Analysis and Stochastics,  
Berlin, Germany*

**Dispersion Relation and Oscillons in  
a Continuum Model for Vibrated  
Granular Media**

*Hermann Riecke, Northwestern University;  
and Jens Eggers, Universität Essen, Germany*

**Control and Synchronization of  
Spatially Extended Systems**

*Ulrich Parlitz and Lutz Junge, Universität  
Göttingen, Germany*

**Prediction of Spatio-Temporal Time  
Series Based on Reconstructed  
Local States**

*Ulrich Parlitz and Christian Merkwirth,  
Universität Göttingen, Germany*

**Wavelet Approach to Hamiltonian Problems**

Antonina Fedorova and Michael Zeitlin,  
Russian Academy of Sciences, St. Petersburg,  
Russia

**Optimal Chaos Control Through Reinforcement Learning**

Sabino Gadaleta and Gerhard Dangelmayr,  
Colorado State University, Fort Collins

**Periodic Solutions of Neutral Functional Differential Equations: A Case Study**

Koen Engelborghs and Dirk Roose,  
Catholique Universiteit Leuven, Belgium;  
and Tatyana Luzyanina, Institute for  
Mathematical Problems in Biology,  
Moscow, Russia

**Dynamical Systems Methods for Geophysical and Environmental Modeling**

Jinqiao Duan, Clemson University

**The Hopf Fibration and its Applications**

Mason A. Porter, Cornell University

**Fractal Dimension in Higher-Dimensional Chaotic Scattering Systems**

David Sweet, Edward Ott, and  
James Yorke, University of Maryland,  
College Park

**Lie Transfer Map Propagation of Perturbed Keplerian Systems**

Liam M. Healy, Naval Research Laboratory

**Exponentially Long Equilibration Times in a 1-D Classical Gas**

Giancarlo Benettin, Università di Padova,  
Italy; and Poul Hjorth, Technical  
University of Denmark

**Thin Liquid Films: Flows On An Imperfect Surface**

Ljubinko (Lou) Kondic, Javier Diez, and  
Andrea Bertozzi, Duke University

**Complex Dynamics in the 1:3 Steady Mode Interaction**

Jeff Porter and Edgar Knobloch,  
University of California, Berkeley

**A Variational Principle for the Amplitude of Limit Cycles**

Rafael Benguria and M. Cristina  
Depassier, P. U. Catolica de Chile,  
Santiago, Chile

**Unstable Periodic Orbits and the Transition to High-Dimensional Chaos**

Ruslan L. Davidchack and Ying-Cheng  
Lai, University of Kansas, Lawrence

**Chaotic Choreography**

Elizabeth Bradley, University of Colorado,  
Boulder; and Joshua Stuart, Stanford  
University Medical Center

**Elimination of Quantization-Induced Limit Cycles in Nonlinear Dynamical Simulations**

Michael G. Bailey and R.H. Cofer,  
Florida Institute of Technology

**Multiple Scales Averaging of Parametric Gain Equations with Periodic Domain Poling**

Richard O. Moore and William L. Kath,  
Northwestern University

**The Breakdown of Shadowing in a Typical Physical System**

Mitrajit Dutta and Edward Ott, University  
of Maryland, College Park; Ernest Barreto,  
George Mason University; and James A.  
Yorke, University of Maryland, College Park

**Nonlinear Polarization Dynamics In Mode-Locked Optical Fiber Lasers**

Arnold D. Kim and J. Nathan Kutz,  
University of Washington; and David J.  
Muraki, Courant Institute of Mathematical  
Sciences, New York University

**Information Transmission Through Chaotic Modeling of Language**

Murilo S. Baptista, Epaminondas Rosa,  
and Celso Grebogi, University of  
Maryland, College Park

**Bifurcation and Dynamics of a Simple Power System Model**

Jon P. Wilson, University of Bath,  
United Kingdom

**Diffusion In Action Space for Weakly Nonintegrable Hamiltonian Systems**

Demin Yao and Jack Shi, University of  
Kansas

**Simulation of Socio-Economic Development in Two Areas Competing for Scarce Resources In Tenerife, Canary Islands**

José Manuel Gonzalez, Universidad de  
La Laguna, Canary Islands, España

**Stochastically Forced Navier-Stokes Equation**

Jonathan C. Mattingly, Stanford  
University; and Ya. G. Sinai, Princeton  
University

**Solitary-Wave Solutions of a Nonlinearly Dispersive Hamiltonian System**

Yi A. Li, Los Alamos National Laboratory

**A Two-Dimensional Biofilm Model with Fingering Instabilities**

Nicholas G. Cogan, Jack Dockery,  
Isaac Klapper, and Mark Pernarowski,  
Montana State University

**1-D Biofilm Models**

L. A. Pritchett, Montana State University

**Particle Dynamics and Mixing In the Frequency Driven Kelvin Cat Eyes Flow**

Elia Eschenazi, Xavier University of  
Louisiana; Yamlak Tsega, Tulane  
University; and Stephen Rodriguez,  
Xavier University of Louisiana

**Wednesday, May 26**

**Poster Session  
and Reception  
Adjourns**

**9:30 PM**

All displays should be completely removed from the poster boards by 10:00 PM.

## Thursday, May 27

For papers with multiple authors,  
*the speaker is shown in italics*,  
 if known at press time.

Thursday, May 27

### Registration Open

7:30 AM-10:00 AM

*Location: Ballroom Lobby*

Thursday, May 27

### IP9

#### DNA Evolution and Computation

8:30 AM-9:30 AM

*Room: Ballrooms I, II & III*

*Chair: Harry Swinney, University of Texas, Austin*

DNA is at the same time the support of genetic information and a polymer. The speaker will describe experiments studying those two aspects. Single stranded DNA can form secondary structures by self hybridization, defining a hairpin-loop. The dynamics of opening and closing of the structure and the elasticity of the loop depends on the information inscribed. The speaker will discuss molecular recognition by annealing the hairpin to a complementary structure, and the optimal sensitivity can be achieved by varying the length and the composition of the stem. He will present a study of microarrays of such hairpin-loops to measure gene expression, and describe protein evolution in the laboratory using ribosome display and a cycle of mutation followed by selection.

**Albert J. Libchaber**  
*Center for Studies in Physics and Biology, Rockefeller University*

Thursday, May 27

### Coffee

9:30 AM-10:00 AM

*Location: Ballroom Lobby*



10:00 AM-12:00 PM  
 Concurrent Sessions

Thursday, May 27

### MS46

#### Modeling of Chaotic Systems

10:00 AM-12:00 PM

*Room: Ballroom I*

Scientists attempt to understand physical phenomena by constructing models, and a fundamental goal is to develop models whose solutions reflect the nature of the physical process. A dynamical model uses simplifying assumptions in the hope of capturing the essential characteristics in the evolution of a physical system over time. The development of models is based on experiments or observations. The speakers in this minisymposium will discuss different approaches to using data to construct models and address the difficulties in modeling dynamical processes with high complexity.

**Organizers: Ulrike Feudel**  
*Universität Potsdam, Germany*

**Celso Grebogi**  
*University of Maryland, College Park*

**10:00-10:25 Obstruction to Modeling**  
 Celso Grebogi, Organizer

**10:30-10:55 Construction of ODE Models from Experimental Data**

*Holger Kantz, Rainer Hegger, and Ralf-Peter Kapsch, MPI Physik Komplexer Systeme, Dresden, Germany*

**11:00-11:25 Reconstruction of High-Dimensional Nonlinear Models from Data**

*Henning Voss and Jürgen Kurths, Universität Potsdam, Germany*

**11:30-11:55 Modeling Multistable Systems**

*Ulrike Feudel, Organizer; and Suso Kraut, Universität Potsdam, Germany*

Thursday, May 27

### MS47

#### Complex Synchronization in Neuroscience

10:00 AM-12:00 PM

*Room: Ballroom II*

Synchronization phenomena in neuroscience are of great current interest particularly for information processing in nervous systems and neurological diseases. The speakers will present new achievements in the understanding of synchronization processes by means of nonlinear dynamics and an approach based on phenomena of hidden phase synchronization recently found in weakly coupled chaotic systems. They will discuss new techniques for the reliable identification of complex synchronization from bi- and multivariate noisy data and to apply this concept to neurophysiological measurements. They will also describe work on complex spatio-temporal dynamics of neural systems.

**Organizer: Jürgen Kurths**  
*Universität Potsdam, Germany*

**10:00-10:25 Detection of n:m Phase Synchronization from Noisy Data**

*Jürgen Kurths, Organizer; Michael Rosenblum, Universität Potsdam; and Peter Tass, Universität Düsseldorf, Germany*

**10:30-10:55 Phase Locked Brain Activity in the Motor System**

*Peter Tass and Alfons Schnitzler, Universität Düsseldorf, Germany; Misha Rosenblum, Universität Potsdam; and Jürgen Kurths, Organizer*

**11:00-11:25 Synchronization of the Stochastic Dynamics of Paddlefish Electroreceptors Cells**

*Frank Moss and Alexander Neiman, University of Missouri, St Louis*

**11:30-11:55 Complex Spatio-Temporal Dynamics of Neural Networks**

*Kazuyuki Aihara, University of Tokyo, Japan*

Thursday, May 27

**MS48****Chaotic Advection in Temporally Chaotic Flows**

10:00 AM-12:00 PM

Room: Ballroom III

Advection in temporally periodic hydrodynamical flows has become one of the most appealing applications of chaos theory with an ample possibility of experimental investigations. In contrast to periodic flows, much less is known about the passive advection in temporally nonperiodic, most interestingly, chaotic flows. They are, of course, more general and have more potential applications including environmental ones. The aim of this minisymposium is to present concepts and approaches to describe advection in temporally chaotic flows and to characterize the degree of chaoticity of these processes, like the concept of indecomposable continua, the use of random maps, fractals, and the way to handle general time dependences.

**Organizers:** Miguel A. F. SanjuanUniversidad Rey Juan Carlos,  
Mostoles-Madrid, España**Tamás Tél**

Eötvös University, Budapest, Hungary

**10:00-10:25 Indecomposable Continua in Fluid Flow Past an Array of Cylinders**

Miguel A. F. Sanjuan, Organizer

**10:30-10:55 Advection in Chaotically Time-Dependent Open Flows**

Tamás Tél, Organizer

**11:00-11:25 Mixing and Diffusion in Aperiodic Flows**

George Haller, Brown University

**11:30-11:55 The Fractal Nature of Vorticity at High Reynolds Number**

Edward Ott, University of Maryland, College Park

Thursday, May 27

**MS49****Applied Dynamics and Invariant Manifolds in Continuum Mechanics**

10:00 AM-12:00 PM

Room: Magpie A/B

Structural mechanics in many systems of interest to defense and industry exhibits nonlinear spatio-temporal dynamical behavior (including chaos) in both theory and experiment. Such fascinating behavior is necessary to understand so that unwanted vibrations may be controlled, and the lifetime of structures may be extended. The papers presented in this minisymposium deal with the mathematical analysis of models and experimental data of nonlinear structures which exhibit nonlinear vibrations and nonlinear modal interactions. The speakers will apply analytic methods to demonstrate that the attractors are finite dimensional, and may be represented by invariant manifolds which slave the motion.

**Organizers:** Ira B. Schwartz and Ioannis T. Georgiou

U. S. Naval Research Laboratory

**10:00-10:25 Nonlinear Normal Modes in a System with Nonholonomic Constraints**

Richard H. Rand and Deepak V. Ramani, Cornell University

**10:30-10:55 Nonlinear Modal Interactions in a Kicked Flexible Rod**

Joseph P. Cusumano, Pennsylvania State University

**11:00-11:25 Exponential Attractors and Inertial Dynamical Systems in Continuum Mechanics**

Basil Nicolaenko, Arizona State University

**11:30-11:55 Proper Orthogonal Decomposition Analysis of the Interaction Dynamics of Coupled Systems in Continuum Mechanics**

Ioannis T. Georgiou and Ira B. Schwartz, Organizers

Thursday, May 27

**MS50****Invariant Manifolds in Oscillation Problems**

10:00 AM-12:00 PM

Room: Wasatch A/B

Invariant Manifolds (center manifolds, hyperbolic manifolds, integral manifolds, etc.) arise naturally in many applied problems such as nonlinear oscillations, communication systems and singular perturbations, in both finite and infinite dimensions. This minisymposium will focus on some recent development of the invariant manifolds theory along with some significant applications to physical problems. By having lectures in different areas of dynamical systems and applications, a primary goal of the minisymposium is to help further research interactions among researchers who are working on fundamental theory of invariant manifolds and applications of invariant manifolds to the qualitative study of differential equations and engineering problems.

**Organizer:** Yingfei Yi  
Georgia Institute of Technology**10:00-10:25 Dynamics of Electronic Oscillators**

Michal Odyneic, Hewlett Packard Co.

**10:30-10:55 Invariant Manifolds and Foliations for Infinite Dimensional Dynamical Systems**

Kening Lu, Brigham Young University

**11:00-11:25 Exchange Lemmas for Singularly Perturbed Problems Certain Turning Points**

Weishi Liu, University of Missouri, Columbia

**11:30-11:55 Singularities of Constrained Differential Systems**

Jorge Sotomayor, Universidade de São Paulo, Brasil

Thursday, May 27

## MS51

### Nonlinear Dynamics in Frontal Polymerization and Combustion

10:00 AM-12:00 PM

*Room: Golden Cliff*

We consider gaseous and solid fuel combustion as well as exothermic frontal polymerization processes, which are used, in particular, to synthesize materials. Since the structure of the material is determined by the propagation mode of the exothermic wave, various modes must be studied. Analytical, numerical and experimental approaches are employed in a variety of problems, including the dynamics of cellular and hot-spot flames and spinning polymerization modes. Since similar instabilities occur in combustion and polymerization, a joint discussion will be beneficial for researchers in both areas. Thus we want to bring together active researchers with interests in flames, combustion and polymerization waves as well as researchers with interests in nonlinear dynamics in general.

**Organizer:** Vladimir A. Volpert  
*Northwestern University*

#### 10:00-10:25 Four States of Motion Unique to the Dynamics of Cellular Flames

Michael Gorman, University of Houston

#### 10:30-10:55 Interaction of Counterpropagating Hot Spots in Solid Fuel Combustion

Bernard J. Matkowsky and A. Bayliss,  
Northwestern University

#### 11:00-11:25 Mathematical Modeling of Frontal Polymerization

Vladimir A. Volpert, Organizer

#### 11:30-11:55 Nonlinear Dynamics In Frontal Polymerization

John A. Pojman, University of Southern Mississippi; and Vitaly Volpert, Université Lyon I, France

Thursday, May 27

## MS52

### Set-Oriented Methods in the Study of Dynamical Systems

10:00 AM-12:00 PM

*Room: Maybird*

Nonlinear dynamical systems are often studied by simply computing long trajectories. This minisymposium presents alternative methods based on set-oriented algorithms for the study of invariant manifolds, chaotic and random dynamical systems and experimental data. These methods provide new insights that could not be obtained by long term simulation. They have applications to spacecraft missions, analysis of experimental time series and bifurcations in chaotic or random dynamical systems. Anyone who is frustrated at the lack of information contained in long term simulations should attend this session.

**Organizers:** Philip J. Aston  
*University of Surrey, United Kingdom*  
Michael Dellnitz  
*Universität Bayreuth, Germany*

#### 10:00-10:25 Computation of Lyapunov Exponents via Spatial Integration with Application to Blowout Bifurcations

Philip J. Aston, and Michael Dellnitz,  
Organizers

#### 10:30-10:55 The Numerical Computation of Rigorous Coverings for Invariant Manifolds

Michael Dellnitz, Organizer, and Oliver Junge, Universität Bayreuth, Germany

#### 11:00-11:25 Symbolic Dynamics for Time Series

Konstantin Mischaikow, Georgia Institute of Technology; M. Mrozek, Uniwersytet Jagiellonski, Krakow, Poland; J. Reiss and A. Szymczak, Georgia Institute of Technology

#### 11:30-11:55 Numerical Approximation of Random Attractors

Hannes Keller and Günter Ochs, Universität Bremen, Germany

Thursday, May 27

## MS53

### Dynamics of Tethered Satellite Systems

10:00 AM-12:00 PM

*Room: Superior A*

Tethered satellite systems, that is, two or more satellites in orbit connected by thin long cables are a new concept of space exploration with great application potential as has been demonstrated by two NASA Space Shuttle flights. The equations of motion are a set of nonlinear, stiff, coupled partial and ordinary differential equations which pose a number of interesting problems both in their analytical and numerical treatment. The nontrivial mechanical and mathematical modelling of such systems due to their changing mass composition and various aspects concerning the mathematical treatment of the equations of motion, such as the occurrence of chaotic motions; stability of relative equilibria; control strategies of deployment/retrieval of a sub-satellite from a mother-satellite and efficient integration algorithms will be discussed.

**Organizer:** Hans Troger  
*Technical University of Vienna, Austria*

#### 10:00-10:25 Modelling and Equations of Motion of Tethered Satellite Systems and Some Simulation Results

Hans Troger, Organizer; and Martin Schagerl, Technical University of Vienna, Austria

#### 10:30-10:55 Nonlinear Dynamics of Tethered Satellite Systems

Arun K. Misra and M. S. Nixon, McGill University, Montréal, Canada; and V. J. Modi, University of British Columbia, Vancouver, Canada

#### 11:00-11:25 Relative Equilibria of Tethered Satellite Systems

Martin Krupa, M. Schagerl, A. Steindl, P. Szmolyan, Technical University of Vienna, Austria; and Hans Troger, Organizer

#### 11:30-11:55 Numerical Treatment of the Relative Equilibrium Equations

Alois Steindl, Technical University of Vienna, Austria

Thursday, May 27

## **MS54**

### **Bifurcation with Euclidean Symmetry**

**10:00 AM-11:30 AM**

*Room: Superior B*

There have been many recent developments in dynamical systems with Euclidean symmetry (or spatially extended systems), with a wide range of applications including Rayleigh-Bénard convection and Ginzburg-Landau theory, the formation and transitions of spirals in reactive media, and the control of underwater vehicles. The speakers in this minisymposium will provide a survey of several of these developments and applications.

**Organizer: Ian Melbourne**  
*University of Houston*

#### **10:00-10:25 Validity, Structure and Universality of the Ginzburg-Landau Equations**

Ian Melbourne, Organizer

#### **10:30-10:55 Underwater Vehicle Dynamics and Stabilization**

*Jerrold E. Marsden*, California Institute of Technology; Anthony Bloch, University of Michigan, Ann Arbor; and Naomi Ehrich Leonard, Princeton University

#### **11:00-11:25 Bifurcations and Dynamics of Spiral Waves**

*Björn Sandstede*, Ohio State University, Columbus; Arnd Scheel and Claudia Wulff, Freie Universität, Berlin, Germany

Thursday, May 27

## **MS55**

### **Dynamics and Nonlinear ODEs in Industrial Applications**

**10:00 AM-12:00 PM**

*Room: White Pine*

The speakers in this minisymposium will discuss problems that arise in industrial applications. The applications are in the telecommunications electronics, and in automotive industries. It is hoped that this session will introduce the audience to the mathematical opportunities in industries.

**Organizers: Rachel Kuske and Fadil Santosa**  
*University of Minnesota, Minneapolis*

#### **10:00-10:25 Input-Output Modeling of Nonlinear Components**

Nicholas B. Tufillaro, Hewlett-Packard Laboratories

#### **10:30-10:55 Nonlinear Control Design for Turbocharged Diesel Engines**

Mrdjan Jankovic, Ford Scientific Research Laboratories

#### **11:00-11:25 Theory and Application of Injection Locking**

Robert Melville, Bell Laboratories, Lucent Technologies

#### **11:30-11:55 Analyzing Multi-Rate Dynamical Systems Using PDEs**

Jaijeet Roychowdhury, Bell Laboratories, Lucent Technologies

Thursday, May 27

## **IP10**

### **Stability and Instability in Dynamics**

**12:15 PM-1:15 PM**

*Room: Ballrooms I, II & III*

*Chair: Shui-Nee Chow, Georgia Institute of Technology, and University of Singapore*

One of the most important problems in Hamiltonian dynamics concerns the stability of near-integrable systems. On one hand, KAM (Kolmogorov-Arnold-Moser) theory states that, in terms of measure, most orbits are stable. On the other hand, one believes that typical high dimensional Hamiltonian systems are topologically unstable, as conjectured by Arnold. The speaker will discuss some of the new methods and results concerning both stability and instability of the Hamiltonian dynamics. In particular, he will discuss the variational method and its applications to Arnold diffusion and various other problems concerning instability.

**Zhihong Jeff Xia**  
*Department of Mathematics, Northwestern University*

Thursday, May 27

## **Conference Adjourns**

**1:15 PM**

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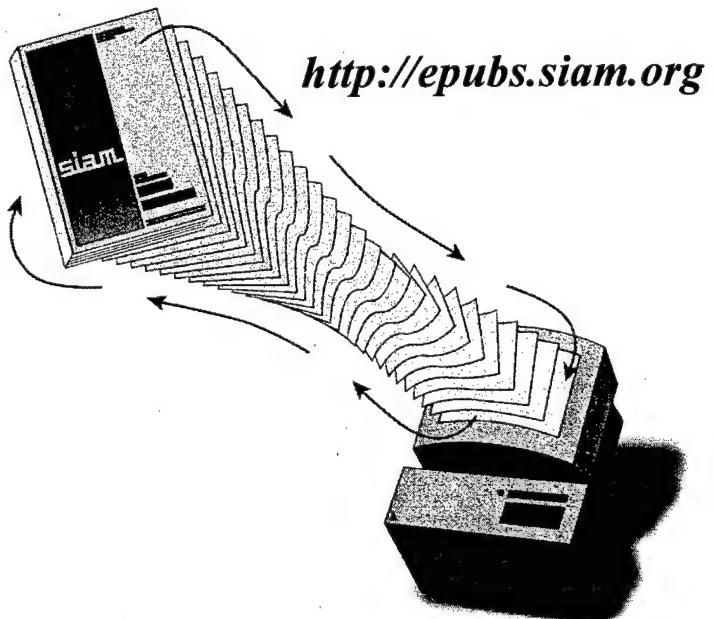
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# ABSTRACTS

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## APPLICATIONS OF DYNAMICAL SYSTEMS

May 23-27, 1999

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.....>

See you in

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2000 SIAM Annual Meeting

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SIAM

**CP01****A Study of Oscillatory Activity in the Model of the Septo-Hippocampal System**

We present an oscillatory model of the septo-hippocampal system with four interactive neural populations (one excitatory and three inhibitory) periodically forced by the entorhinal cortex. Using bifurcation analysis we found dynamical modes with fast (40 Hz, gamma-rhythm) and slow (5 Hz, theta-rhythm) oscillations. These results are in a good agreement with experimental evidence on septo-hippocampal dynamics both in normal conditions and under different lesions. We discuss applications of this model for memory and learning.

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**CP01****Dimension Estimation for Seizure Prediction and Localization**

By comparing several methods for estimating the dimension of time series from electroencephalograms (EEG) of patients obtained during presurgical evaluation for intractable epilepsy, we were able to develop a composite approach which proved to predict seizure onset time and location with greater accuracy than previously-applied algorithms.

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**CP01****Rate-Dependent Activity in Excitable Cells**

We analyze a model of spontaneous secondary spike initiation in a neuron. The mechanism of spontaneous spike generation is analogous to that causing the repetitive activity in squid axon due to an applied current. A combination of bifurcation analysis and numerical computations indicates that spontaneous secondary spikes occur when a particular parameter rests near a saddle-node of periodics bifurcation point. A similar analysis suggests why certain experimental interventions promote triggered activity in cardiac cells.

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**CP01****Understanding Interspike Interval Variability**

In the past investigators have shown that a constant current injected into a neuron results in a highly variable response, while injection of a variable (i.e. random) current

results in a more reliable response. We supply evidence that this phenomenon is dependent upon the previous history of the neurons. By setting the membrane potential history we can account for significant features in the variability of the response.

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**CP01****Synchronous Behavior of Two Coupled Biological Neurons**

We report experimental studies of synchronization phenomena in a pair of biological neurons that interact through naturally occurring, electrical coupling. When these neurons generate irregular bursts of spikes, the natural coupling synchronizes slow oscillations of membrane potential, but not the fast spikes. By adding artificial electrical coupling we studied transitions between synchrony and asynchrony in both slow oscillations and fast spikes. We discuss the dynamics of bursting and synchronization in living neurons.

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Henry D.I.Abarbanel  
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 Scripps Institution of Oceanography  
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**CP01****Genesis of Coherent Structures in a Discrete Chaotic Neural Medium**

We disclose the origin of large scale coherent structures in a discrete nonequilibrium medium of locally interacting chaotic neurons with fast and slow oscillations. Introducing the concept of 'coarse grain' as a cluster of neurons with periodic averaged behavior allows consideration of the dynamics of a new medium composed of these clusters. Ordered, quasi-steady, large scale patterns are revealed in the slow dynamics controlled by the average intensity of the chaotic rapid pulsation.

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**CP02****Connecting Double Points in Rayleigh-Bénard Convection**

We consider steady, 2-D, viscous incompressible flow between parallel plates, the bottom of which is heated (Rayleigh-Bénard convection), and periodic in the other direction. Using two-parameter pseudo-arclength continuation, we compute the bifurcation diagram in the (period, Rayleigh number) plane in the neighborhoods of the crossings (double points) of several pairs of neutral stability curves. We discover several secondary bifurcation paths connecting pairs of these crossings.

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**CP02****Laminar and Turbulent Energy Dissipation in a Shear Boundary Layer with Suction**

The rate of viscous energy dissipation in a shear layer of incompressible Newtonian fluid with injection and suction is studied by means of exact solutions, nonlinear and linearized stability theory, and rigorous upper bounds. We find that the upper bound on the energy dissipation rate, valid even for turbulent solutions of the Navier-Stokes equations, scales precisely the same as that in the lami-

nar exact solution with regard to the viscosity as  $\nu \rightarrow 0$ .

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**CP02****Time-Dependent Flow Regimes in Two-Phase Flows and Compressible Fluids**

Traveling waves (of voidage) are observed to move through fluidized gas-particle suspensions (fluidized beds) as well as other two-phase flows. In order to gain an understanding of the mechanics of such voidage waves, a bifurcation analysis has been used to capture the evolution of instabilities in a compressible fluid which is acted upon by a density dependent force. These instabilities take the form of density waves which resemble the voidage waves in fluidized beds.

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**CP02****Spatial and Temporal Resonances in a Periodically Forced Extended System**

The occurrence of a Naimark-Sacker bifurcation in a periodically forced spatially extended system is analyzed with Floquet theory. Windows in parameter space where onset of instability is via Naimark-Sacker correspond to forcing frequencies close to the natural frequencies of the unforced system when the forcing amplitude is sufficiently large. In these windows, not only have strong temporal resonances been identified, but also competition and resonances between various spatial modes that are simultaneously excited take place. An excitation diagram mapping out these windows and loci of resonance points is produced, providing a guide for future explorations into the nonlinear regime by either experimental or computational techniques.

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**CP02****Stability Analysis of Perturbed Plane Couette Flow**

Plane Couette flow is linearly stable at all Reynolds numbers, but undergoes sudden transition to turbulence experimentally and numerically near  $Re=300$ . Searching for intermediate states by inserting a wire into the flow, experimentalists observe 3D steady states containing streamwise vortices. Using a spectral-element code, we show that these states arise via subcritical pitchfork bifurcation. We investigate the transition to time-dependence, and the dependence of the scenario on wire radius.

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**CP02****Asymptotic Regime of the Rayleigh-Taylor Instability in the large-time Limit**

We propose a variational method for the description of the asymptotic regime of the Rayleigh-Taylor instability when  $t \rightarrow \infty$ . To describe the dynamics of a highly curved interface, we use a time dependent conformal mapping. In the simplest case, when there is a single symmetric finger, we obtain a simple integrable Hamiltonian system. We discuss its solution and physical implication.

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**CP03****Chaos Communications Using Virtual Synchronization**

Virtual synchronization is presented as a new technique for practical communication using chaotic waveforms. Compared to methods using conventional synchronization, virtual synchronization does not require strict correlation of system states; rather, it requires that only limited characteristics of the source system are matched by the response system. As a result, communication with virtual synchronization is more tolerant to channel noise, narrowband interference, signal fading, and bandwidth limiting than other synchronization-based techniques.

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**CP03****Theory of Wavelength Division Multiplexing in Fiber Links with Dispersion Management**

Wavelength Division Multiplexing (WDM) is an important technique used in modern optical fiber telecommunications. This technique consists of dividing the window of a fiber's optical transparency into several frequency channels, and transmitting the information through all channels in parallel. We will present an introduction to the theory of soliton communications for WDM and a review of experimental results. The physical limitations, such as four-wave mixing due to interchannel interaction and polarization mode dispersion, will also be explained. We will discuss several aspects of WDM including dispersion management and distributed amplification for high bit-rate optical data transmission. In many cases, WDM data transmission can be described in terms of a system of coupled nonlinear Schrödinger equations. We will present a mathematical approach for finding analytical solutions of such systems.

Ildar Gabitov

Theoretical Division, Los Alamos National Laboratory  
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**CP03****Polarization-Based Laser Communication Schemes**

Laser-based chaotic communication has recently been demonstrated using pairs of erbium-doped fiber-ring lasers. Such lasers exhibit dynamics which involve both polarization states of light in a fundamental way. We consider a simplified laser model based on vector Maxwell-Bloch equations and explore the dynamics for different couplings between the fundamental polarization modes. In particular, we analyze message security using various communication schemes. We also comment on results based on actual experimental data.

John B. Geddes and Kevin M. Short

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**CP03****Multiple-Scale Averaging and Optimization of Amplifier Placement in Multi-Channel Dispersion-Managed Soliton Transmission**

We analyze the nonlinear Schrödinger equation using multiple-scale averaging to investigate a simple design of two-step dispersion maps that are advantageous for wavelength-division-multiplexing. We show that for any ratio of the lengths of the fiber segments comprising a map, one can obtain a choice of amplifier placement that allows simultaneous minimization of dispersive radiation in several different channels. We also investigate the effect of the amplifier placement on the power enhancement of the dispersion-managed soliton.

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**CP03****Premature Synchronisation in Coupled Maps**

Recently, there has been immense interest in the phenomenon of synchronization of coupled oscillators. The stability of an invariant state in the coupled systems is determined by the sign of the largest transverse Lyapunov exponent, a quantity which frequently decreases with increasing coupling strength, until stability is obtained. In this paper, we report simple cases in which analytic representations of the threshold stability coupling strength are obtainable, but are not in agreement with numerics. This phenomenon is discretization induced, and is well explained by the use of cell-mapping techniques.

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**CP03**  
**Security Issues in Chaotic Communications**

We consider security in new chaotic communications techniques. Hybrid techniques using encryption and chaotic communication are considered, and we show circumstances under which it is possible to extract the hidden signals. We introduce a new technique which employs a digital (control/no control) link between chaotic transmitter and receiver, where remote initialization is possible, but the transmitted information is independent of the state of the chaos, so unmasking by nonlinear dynamic forecasting fails completely.

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**CP04****Singular Poincaré-Andronov-Hopf Bifurcation to Relaxation Oscillations During High-Speed Metal Cutting**

We have developed a new model for chip formation in high-speed machining that is similar to models of open chemical reactors. We show that, as the tool cutting speed is increased, a singular Poincaré-Andronov-Hopf bifurcation occurs in the model. This provides an explanation for the change from continuous to segmented chip formation that

is observed in most metals as cutting speed increases.

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**CP04****Symmetry-Breaking Bifurcations in a Hopf/Steady-State Mode Interaction in Three-Dimensional Magnetoconvection**

Mode interactions in 3D convection have received little attention, despite their physical relevance. In magnetoconvection we can find a point where the conduction state is unstable to both steady and oscillatory motion simultaneously and it is possible to apply weakly nonlinear theory. Physical symmetries play a large role in determining the bifurcation structure and explain the appearance of interesting phenomena like drifting solutions. Weakly nonlinear analysis elucidates the complex transition between steady and oscillatory convection.

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**CP04****Double Hopf Bifurcation in a Geophysical Fluid Dynamics Model**

We show, using center manifold reduction, that in a model of large scale atmospheric flow double Hopf bifurcations lead to two simultaneously stable periodic solutions (two travelling waves with different wave numbers) in the geophysically relevant range of parameters. The results, which are observed for several pairs of wave numbers, indicate hysteresis of the wave solutions. The eigenfunctions of the model cannot be found analytically and therefore they must be found numerically. This leads to numerical approximations of the normal form coefficients.

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**CP04****Thermo-Acoustic Instabilities in Aeropropulsion Systems**

Lean premixed combustors are inherently susceptible to thermo-acoustic instabilities, in which the interaction be-

tween the chemical kinetics and the underlying fluid flow serves to excite an acoustic response within the enclosed volume of the combustor. This problem is studied with the goal of obtaining reduced-order dynamical models which capture the self-excited oscillations seen in real gas turbine systems. A linear analysis is used to describe the stability of the time-independent solution, while asymptotic methods are employed to decouple the reaction-diffusion equations governing the transport and combustion of the reactant from the equations governing the fluid flow.

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#### **CP04**

#### **Visual Interpretation of Transitions in Spatiotemporal Systems**

Empirical analysis of bifurcations in simulations and laboratory experiments requires the comparison of spatiotemporal data sets acquired at several parameter values near the transition point. This paper develops visual techniques for comparing such spatiotemporal collections based on three general approaches: visual tiling, summary extraction and abstraction, and projection on a common coordinate system. The techniques are illustrated by an analysis of video data from an experimental survey in a combustion experiment near the extinction boundary.

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#### **CP05**

#### **A Model of Central Pattern Generators for Quadruped Locomotion**

It is known that gaits of quadrupeds are periodic and symmetric motions. We model the Central Pattern Generators (CPGs) for quadruped locomotion using coupled cell systems (cell=ODE). Our approach uses equivariant bifurcation theory. We present a network of symmetrically coupled cells modeling the CPG for locomotion of quadrupeds. The network produces periodic solutions with phase shifts of common quadruped gaits. We show that bifurcations from the periodic solutions lead to periodic solutions of gaits adopted at higher speeds. We discuss the stability of the periodic solutions and show that our network model is the simplest one under certain modeling assumptions.

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#### **CP05**

#### **Normal Forms via Non-Normal Means**

Normal forms have proven to be a powerful tool for investigating the bifurcation structure of nonlinear dynamical systems. There exists a standard procedure on the space of vector valued monomials for systematically removing nonlinear terms from the original dynamical system. However, the procedure has no convergence guarantees and often produces systems with discouragingly small regions of validity. We present a generalization of the technique on a different space with much improved results.

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#### **CP05**

#### **Heteroclinic Cycles in Networks of Cells with $D_n$ -Symmetry**

In this work, we investigate the existence and stability of intermittent cycles involving steady states and periodic solutions in networks of coupled cells with  $D_n$ -symmetry. Based on the lattice of isotropy subgroups, we study the vector field restricted to invariant fixed-point subspaces. When certain conditions are satisfied, we prove that it is possible to have asymptotically stable cycles connecting periodic solutions with steady states and periodic solutions with periodic solutions.

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#### **CP05**

#### **Chaotic Direction-Reversing Waves**

Secondary bifurcations in systems with  $O(2)$  symmetry are studied with emphasis on different codimension one mechanisms generating nonlinear waves that reverse their direction of propagation in a chaotic fashion. The mechanisms are illustrated using the normal form for the triple zero bifurcation with  $O(2)$  symmetry and involve parity-breaking bifurcations of standing waves or global connections involving circles of standing waves and/or steady states. Applications to fluid convection are described.

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a harmonic pulse with a small, slowly-varying amplitude yields a nonlinear Schrodinger-type equation for the electric field envelope. Expansions are performed on the Lax pair as well as the equations to ensure integrability is retained. Dynamics of the solutions in this limit are compared analytically and numerically.

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### CP05

#### Bursts in Oscillatory Systems with Broken D<sub>4</sub> Symmetry

A new mechanism responsible for generating regular and irregular bursts of large dynamic range near onset of an oscillatory instability is identified. The bursts are present in systems with nearly square symmetry and are the result of global connections involving infinite amplitude states created when the square symmetry is broken. The intricate sequence of bifurcations that take place is described in several cases, and the possible relevance of the results to experiments is discussed.

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### CP06

#### Bi-Instability and Ultrasubharmonics in a Modulated Laser

Bi-instability, in contrast of bistability, is shown to generate unstable chaotic saddles prior to chaos in a laser with modulated losses. Theory and numerics are used to show that: (i) Unstable saddles form heteroclinic connections that allow mixing between chaotic attractors to produce mixed-mode chaos. (ii) Ultrasubharmonic orbits can generate long-period but low-amplitude laser response.

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### CP05

#### Doubly Forced Oscillators

We consider models of doubly forced planar oscillators of the form:

$$\dot{x} = F(x) + \alpha\{(1 - \gamma)G_1(x, n\omega t) + \gamma G_2(x, m\omega t)\}.$$

The forcing frequency  $\omega$  and forcing amplitude  $\alpha$  are primary parameters;  $\gamma$ , controlling the relative amplitudes of forcing, is an auxiliary parameter. Perturbing  $\gamma$  from zero or one results in symmetry breaking of a Hopf bifurcation. Running  $\gamma$  between zero and one "melts" a period- $q_1$  resonance region (Arnold horn) into a period- $q_2$  region and provides a natural example of "Arnold flames."

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### CP06

#### Dynamics of Wavelength-Division-Multiplexed Transmission of Return-to-Zero Pulses in Dispersion-Managed Optical Fibers

We analyze wavelength-division-multiplexed transmission of return-to-zero pulses in a dispersion-managed optical fiber. An accurate ODE model for the pulse dynamics is constructed and integrated analytically for piecewise-constant dispersion maps. The analytic theory enables one to efficiently evaluate the performance of various system arrangements. An optimized system design is then identified, which produces unchirped output pulses across a practical wavelength range without the need for channel-by-channel fine-tuning.

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### CP06

#### Dynamics of Low-Amplitude Resonant Light-Matter Interaction

The ideal Maxwell-Bloch equations describe lossless, resonant interaction of light with a two-level optical medium. With the medium in the ground state, expanding about

### CP06

#### Self-Pulsations of a Lasers with Saturable Absorber

We consider the three-dimensional Yamada system, a simple model for self-pulsations in (semiconductor) lasers with

saturable absorber. By identifying a Bogdanov-Takens bifurcation as an organizing center we show that pulses are created in a homoclinic bifurcation, as was conjectured in earlier work. For realistic values of the parameters this homoclinic bifurcation practically coincides with the laser reaching its threshold, which explains why it was not found earlier.

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#### **CP06** **Controlling Resonant Wave Interactions to Enhance Frequency Conversion in Nonlinear Optics**

Efficient frequency conversion of light waves is realized in nonlinear optics using piece-wise constant controls. The  $N$ -wave equations model this process. A convenient setting in which to analyze their control is obtained using Poisson reduction. Symmetries that produce phase shifts are factored out and the amplitude dynamics are projected onto a reduced phase space. In this geometrical setting controls for four-wave and multiply-resonant quadratic interactions are obtained.

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#### **CP06** **Estimating Parameters in Laser Dynamics**

In nonlinear optics, comparison between experiment and theory is usually performed qualitatively by visually comparing measured data to simulations of the corresponding differential equations. It can not be decided whether possible discrepancies are due to wrongly chosen parameters in correct models or whether it is the models themselves which are actually incorrect. We show that the parameters of the differential equations can be estimated from the data and that models can be compared statistically.

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#### **CP07**

#### **Homoclinic and Heteroclinic Orbits for Singularly Perturbed nearly Integrable Systems**

We study nearly integrable 3-dimensional systems devised by Doelman and Hek based on the complex Ginzburg-Landau equation. Solutions of interest for this system are single and multiple pulse homoclinic and heteroclinic orbits which correspond to traveling localized structures in the Ginzburg-Landau equation. Using geometrical singular perturbation arguments, Doelman and Hek proved that for each integer  $N \leq O(|\ln \epsilon|)$  there are two  $N$ -pulse orbits. We use shooting arguments to improve their estimate to  $N \leq O(1/\epsilon)$ .

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#### **CP07**

#### **Homoclinic Bifurcations and Chaos in the Presence of a Center Manifold**

We consider differential equations consisting of hyperbolic and center parts and use our previous generalized Melnikov theory to find a transverse homoclinic orbit for the hyperbolic part. We construct a topological conjugacy between a multiple of the period map for the hyperbolic flow and the Bernoulli shift through Palmer's construction which uses chaotic jumping solutions. With damping and applied forcing the center part becomes weakly attracting and with this we can shadow Palmer's jumping solutions extending the topological conjugacy to the full equation. The theory is applied to vibrating elastic beams.

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#### **CP07**

#### **Slow Passage Through a Saddle-Center Bifurcation**

Slowly varying potentials are analyzed. Away from homoclinic orbits, strongly nonlinear oscillations are obtained using the method of averaging. For a saddle-center bifurcation, solutions consist of a large sequence of nearly saddle-center homoclinic orbits connecting autonomous nonlinear saddle approaches, and the change in the action is determined. However, a saddle approach with particularly small energy is nonautonomous, and may also provide a transition to small oscillations around the center.

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#### **CP07**

#### **Homoclinic and Heteroclinic Orbits in Cylinder Buckling**

We investigate the post-buckling regime of a cylindrical shell this exhibits an initially unstable response that then restabilizes with the formation of localized buckles in a cell.

As buckling continues over a growing number of cells the response can be described by a set homoclinic connections. In the limit, this leads to a heteroclinic connection from the fundamental unbuckled state to a post buckled state that is periodic. We describe this phenomena and present some numerical results.

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#### **CP07**

#### **Heteroclinic Bifurcations as the onset of Voltage Collapse in a Power System Model**

We investigate a widely used four-dimensional power system model exhibiting voltage collapse. With the reactive power demand as a bifurcation parameter, we find a heteroclinic bifurcation between the one-dimensional unstable manifold of a saddle equilibrium and the three-dimensional stable manifold of a saddle periodic orbit. This results in severe shrinking of the basin of attraction of the operating point. We believe that here lies the onset of voltage collapse and illustrate our findings with numerical computations.

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#### **CP07**

#### **Homoclinic and Heteroclinic Motions for Resonant Periodic Orbits in Forced, Two-Degree-of-Freedom Systems**

We study homoclinic and heteroclinic motions in periodic perturbations of two-degree-of-freedom Hamiltonian systems having a saddle-center with a homoclinic orbit. We assume that the primary resonance occurs near the unperturbed saddle-center and apply a Melnikov-type approach and the averaging method to obtain criteria for the existence of transverse homoclinic and heteroclinic orbits to periodic orbits near the saddle-center. To illustrate the theory we give an example for the forced, coupled Duffing oscillators.

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#### **CP08**

#### **Propagation of Phase Transformation Front In 1D Shape Memory Allow Induced by Impact Loading**

We study phase transformation propagation in quasi-1D semi-infinite SMA rod in the framework of constitutive theory due to Bekker/Brinson and Boyd/Bo/Lagoudas. This theory with martensite fraction serving as internal variable was developed for SMA materials with transformation hardening behavior (monotone nonconvex stress-strain relation). First we study impact problem in isothermal setting, that provides an important insight on the structure of the solution, and then adiabatic-isoentropic approximation is used to find shock adiabat-isoentrope of 1D SMA body with linear kinetics. Numerical results obtained for the full system of equations are in excellent agreement with analytical results for adiabatic-isoentropic model. The non-uniqueness issue inherent to wave propagation problems in SMA materials due to nonconvex constitutive law is thoroughly discussed.

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#### **CP08**

#### **Critical States and Minima for an Energy with Second Order Gradients**

Coleman, Marcus & Mizel [1992] studied the thermodynamical equilibrium of second-order materials and showed that in certain regimes such materials must exhibit equilibrium states that are nonuniform by proving that space-periodic solutions can have lower energy than space-uniform ones. A dynamical systems approach is used here and it is shown that there is a critical value of the mean concentration. When the mean concentration crosses this critical value, the uniform state can lose its minimizing character and periodic or quasiperiodic states can have lower energy. The presence of that critical value corresponds to a 1:1 resonance.

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#### **CP08**

#### **An Integrodifferential Model of Phase Separation**

In this talk we shall consider two aspects of the order parameter non-preserving model of phase separation based on the Khachaturyan free-energy functional in a finite domain

$\Omega \subset \mathbf{R}^n$ , namely,

$$u_t = \epsilon \int_{\Omega} J(|x-y|)(u(y) - u(x)) dx - f(u),$$

where  $f(u)$  is bistable. We discuss the behaviour of the dynamical system generated by the above equation, in particular the existence and structure of a compact attractor and display numerical experiments of coarsening in this system which is very different from that of the Allen-Cahn equation.

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#### CP08

#### Disjoining Potential and Spreading of Thin Liquid Layers in the Diffuse Interface Model Coupled to Hydrodynamics

The hydrodynamic phase field model is applied to the problem of film spreading on a solid surface. The disjoining potential, responsible for modification of the fluid properties near a three-phase contact line, is computed from the solvability conditions of the density field equation with appropriate boundary conditions imposed on the solid support. The equation describing the motion of a spreading film are derived in the lubrication approximation. In the case of quasi-equilibrium spreading, is shown that the correct sharp-interface limit is obtained, and sample solutions are obtained by numerical integration. It is further shown that evaporation or condensation may strongly affect the dynamics near the contact line, and accounting for kinetic retardation of the interphase transport is necessary to build up a consistent theory.

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#### CP08

#### Nucleation Dynamics of Cahn-Hilliard Equation

We discuss the nucleation dynamics of Cahn-Hilliard equation, a widely accepted model for some complicated behavior of the concentration of a binary alloy. Precise informa-

tion on the spike-like steady state solutions and estimates on associated eigenvalue problems will be given.

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#### CP09

#### Intermittent Phase Transitions in a Two-Dimensional Stick-Slip Model of Earthquakes

Stick-slip behavior of a spring-block oscillator in two dimensions is studied. The comparison to the case of one-dimensional stick-slip reveals intrinsic differences of the present model, consisting in the necessity to use a modified friction-velocity relation, and emergence of intermittent switching between creep and slip phases of motion. The principal role of asymmetric elastic forces is investigated, and the necessary conditions for the existence of intermittency are obtained. The prospects of the model for the problem of earthquake prediction are discussed.

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#### CP09

#### Dynamics and Control of a Constrained Impact Oscillator

We model a feedback-assisted actuator as an impact oscillator constrained between two parallel walls. The dynamical behaviour, seen as a Poincaré map, is compared to a stroboscopic data set obtained from an experimental model. Whereas some topological features correspond to undesirable impacting behaviour, in other cases periodic impacts may be a required feature of engineering applications. We analyze the stability of some orbits, and finally we apply OGY control algorithms on the impact map.

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#### CP09

#### Asymptotic Behavior in a Two Degree of Freedom Mechanical System with a Stop

We study the dynamics of a two degree of freedom, piecewise linear, frictionless, unforced, mechanical system constrained by stops. The system is governed by three types of dynamics: coupled harmonic oscillation, simple harmonic motion and discrete rebounds. Energy is dissipated discon-

tinuously in discrete amounts, through impacts with the stops. This dissipation mechanism, coupled with the qualitatively different behaviors allowed by the hybrid dynamics, results in a rich global limiting asymptotic behavior which we characterize.

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#### **CP10**

#### **Low-Dimensional Atmospheric Models at Various Truncations**

By making use of empirical orthogonal functions (EOFs) and experimental corrections, an atmospheric model is obtained that can be truncated at arbitrary low dimensions and behaves quite realistically above approximately 30 dimensions. Results will be presented of an investigation into the dependence of the dynamical properties on the model truncation, using bifurcation analysis. The convergence of the bifurcation diagram and robustness of certain dynamical characteristics above 30 dimensions are key issues of this investigation.

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#### **CP10**

#### **Finite Difference Balance Models**

We study numerical solutions of the reduced-gravity shallow-water equation on a beta plane, subjected to a sinusoidally varying wind forcing leading to the formation of a double gyre circulation. A method is presented, applicable to any finite-difference scheme, that effectively increases the spatial resolution of the given algorithm without changing its temporal stability or memory requirements. This *enslaving* method makes use of the geostrophic balance of the flow to reduce the overall truncation error. By examining statistical measures of stochastic solutions, we show that the enslaved schemes are capable of reproducing statistics of standard schemes computed at twice the resolution.

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#### **CP10**

#### **Global Bifurcation in a Simple Ocean Model**

We demonstrate the existence of a global bifurcation sequence in a simple ocean model, the equivalent barotropic quasi-geostrophic model. All previous studies of this model

in the context of single and double gyre circulations have demonstrated various bifurcations, but all of which are local in nature. The complicated bifurcation sequence that we demonstrate is sometimes called the Shilnikov phenomenon and involves a somewhat novel applications of power spectra and proper orthogonal decomposition techniques.

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#### **CP10**

#### **Reversals and on-off Intermittency in the Dynamics of the Convective Dynamo**

The nature of the dynamo action is investigated in a kinematic dynamo forced by heteroclinic and chaotic convective velocity fields resulting from a bifurcation analysis of the spherical Benard problem. Reversals of poles, chaotic and on-off intermittent behavior of the magnetic field are obtained. The relevance of this form of intermittency to the dynamics of sunspots is discussed. An antidynamo conjecture suggested by the numerical experiment is analyzed.

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#### **CP10**

#### **A Low-Dimensional Climate Model II**

A five dimensional model is studied which combines the Lorenz-84 model for the atmosphere, and Stommel's 2-box model for the ocean. The time scales of these models are very much different. Varying the coupling parameters, regular as well as chaotic behaviour is found. In the transition to chaos intermittency is observed. This is explained by means of bifurcation and stability analysis. The slow dynamics of the ocean model plays an essential role.

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#### **CP10**

#### **A Low-Dimensional Climate Model I**

We present a low-dimensional ocean-atmosphere system based on coupling of the atmospheric Lorenz-84 model and Stommel's 2-box ocean model. The coupling involves heat and water/vapour transport. One of the intriguing problems of this system is the part played by the very different time-scales of its components. We discuss some aspects of the bifurcations and the presence of intermittency.

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**CP11****A Kinetic Model for Granular Media**

We present a kinetic model for granular media. The model incorporates all the effects of inelasticity, rotational freedom and volume-exclusion. Both asymptotic solution and numerical simulation of the model show that the volume-exclusion has a significant effect on the energy distribution between rotational and translational motions. Such an effect has been ignored in the literature. The evolution of the statistical quantities exhibits interesting features with the variation of inelasticity.

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**CP11****Molecular Dynamic Simulations of Clusters in Sheared Granular Materials**

A molecular dynamic simulation has been used to examine the effect of cluster formation on stress and other macroscopic quantities in a rapidly sheared granular material. The shear flow evolves to a dynamic system of clusters, which form and break up as time progresses. It is observed that the stress increases with the degree of clustering and there is weak scale separation between the microscopic and macroscopic scales.

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**CP11****About Motion of Spherical Particles on a Surface**

Using theoretical analysis and molecular dynamics simulations, we explore 2D system of spherical particles. Paying particular attention to the modeling of the frictional interaction of the particles with the substrate, we discuss transfer of energy from the particles to the substrate and possibility of formulation of a continuum theory. We observe that, due to this frictional interaction, the inelastic collapse is not observed.

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**CP11****Spontaneous Chaotic Granular Mixing**

Instabilities leading to spontaneous chaotic mixing have a rich history in fluid mechanics. By contrast, in granular flows mixing is believed to be diffusive, and spontaneous chaotic behavior has not previously been reported. In the presence of stick-slip motion, however, we find the spontaneous emergence of intricate mixing patterns which we duplicate in an explicit continuum model. Both model and experiment produce exponentially rapid, chaotic, mixing.

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**CP12****Dynamics of Human Blood Distribution System**

We demonstrate that five almost periodic processes are mutually coupled to govern the dynamics of blood distribution in humans. Using wavelet transform, four characteristic peaks with slowly varying amplitudes and frequencies were found in the heart rate variability on the time scale of blood distributive processes. Peaks at almost the same frequencies were also found in blood flow, pressure and respiratory signals, together with the fifth peak at the heart rate. We discuss changes in the frequency content in some cardiovascular diseases.

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**CP12****Modelling the Control of Ovulation in Terms of Gonadotropin Receptors in Granulosa Cells**

The primary mechanism controlling ovulation in primates is believed to rely on a competitive process between a group of developing follicles. Such competition is mediated through a hormonal feedback loop involving the pituitary gland. However, little is known about how these follicles react to the pituitary hormones. We present an ordinary differential equation model which explicitly describes follicular sensitivity to gonadotropins in terms of the equilibrium concentration of bound receptors in the granulosa cells.

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**CP12****Respiration by Turbulant Diffusion in Frogs**

A turbulent diffusion column ventilates the lungs of resting frogs of several species, whereby throat movements (gular undulations) exchange gas in the buccal cavity with ambient air through open nares and with pulmonary gas through an open glottis. Oxygen and carbon dioxide diffuse along respective concentration gradients. Gular undulations contribute turbulence to the diffusion producing a space time fractal. A model using inhaled tantalum particles permits visualization of random walk trajectories leading to turbulent flows.

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**CP12****The Mechanics of Lung Tissue Under High-Frequency Lung Ventilation**

High frequency lung ventilation has been shown to benefit patients with severe respiratory distress, but may also induce lung damage, and a clear protocol for the most effective treatment has not been identified. We use a homogenisation theory approach to derive equations for the macroscopic behaviour of lung tissue based upon the microstructure of respiratory regions. This, in combination with larger scale numerical simulations, forms the first step towards a predictive model to aid clinical decision making.

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**CP12****Cardiorespiratory Interaction in Anesthesia**

The cardiac and respiratory systems are known to be oscillatory and mutually coupled; their coupling is manifested in the heart rate variability (HRV). Using the time-frequency analysis we show that in anesthetized rats the energy of the HRV is significantly reduced. Additionally,  $n : m$  frequency synchronization, but no single phase locking between heartbeat and respiration were observed. The depth of anesthesia can be characterized by the frequency ratio of those two coupled oscillators, as well as by the extent of the HRV.

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**CP12****Subcellular Mechanisms for the Regularization of Neural Bursting Activity**

An essential question raised after the observation of highly variable bursting activity in individual neurons of central pattern generators is how an assembly of such neurons can cooperatively produce regular signals to motor systems. Periodic driving or mutual inhibitory connectivity are mechanisms that regulate this behavior. We discuss how slow subcellular dynamics such as luminal calcium oscillations may play an important role in the genesis and regularization of the chaotic activity observed in the experiments.

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**CP13****The Contraction of the Asymptotic Solutions of the System of Differential Equations with Deviating Argument**

The Construction of the Asymptotic Solutions of The system of differential equation with deviating argument. The communication deals with the initial-value problem for the system of linear differential equations with slowly varying coefficients and with lagging argument.

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**CP13****Delay-Differential Equations with a Large Delay: Application to Semiconductor Laser Instabilities**

Semiconductor lasers have a lot of applications but are extremely sensitive to optical feedback. The problem is modeled mathematically by delay-differential equations where the delay is large compared to the laser time constants. This motivates the study of system of delay-differential equations exhibiting a weak feedback but a strong delay. We show that this delay leads to multiple branching of peri-

odic solutions as well as secondary bifurcation to quasiperiodic oscillations.

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**CP13****Numerical Methods for Delay Differential Equations: New Approach, Software Package, Applications**

We present an approach to constructing of numerical methods for Delay Differential Equations. The approach is based on the constructions of a new i-smooth calculus of nonlinear functionals. On the basis of this approach the Time-Delay System Toolbox is elaborated. Applications of the Toolbox for simulating and analysis of specific time-delay models are discussed.

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**CP13****Existence of Periodic Solutions for a State Dependent Delay Differential Equation**

We present a model of population dynamic with provide a state dependent delay equation. We then consider the problem of finding non trivial periodic solutions for this state dependent delay differential equation. The equation was introduced by Arino, Hadeler, Hbid (1998). In this work we prove the existence of slowly oscillating periodic solutions, by using a new approach.

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**CP13****On the Stability of Neutral Functional Differential Equations**

This talk concerns the behaviour of the essential spectrum of neutral functional differential equations. We emphasize on limit cases whereby some of the delays are brought to zero or asymptotically coincide, which may lead to eigenvalues moving to infinity. Necessary and sufficient conditions are provided. Thereby the ratio of the delays plays a crucial role. The theory can be applied to analyze the robustness of boundary controlled PDEs in the presence of small feedback delays, as will be illustrated by examples.

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**CP14****Vanishing Twist near Resonances in Symplectic Maps**

Using normal forms we show that in the neighborhood of an elliptic point of an area preserving map with multiplier a third root of unity the twist vanishes. As a corollary it follows that the collision of Poincare-Birkhoff island chains with the same winding number close to a twist-less curve is generic in area preserving maps. The same phenomenon is analyzed in a four dimensional symplectic map, where also another low order resonance makes the twist vanish close by.

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**CP14****Volume-Preserving Reduction by Symmetry**

Reduction by symmetry of N-dimensional volume-preserving dynamical systems admitting volume-preserving symmetries is discussed, extending previous theories for three-dimensional systems.

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**CP14****Size Matters in Small One-Dimensional Lattices**

We examine how the well-known continuum scaling of a chain with nonlinear nearest-neighbor interactions falters and then fails. As the system size shrinks, continuum behavior yields to a discrete regime which is explicitly size dependent. The transition between regimes occurs at a critical value of system size that coincides with the onset of instability. The parity of the inter-particle potential strongly influences the transition to the small-chain limit.

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**CP14****Quadratic Volume Preserving Maps: Normal Forms and Dynamics**

We consider quadratic, volume preserving maps that have a quadratic inverse. In  $R^3$  the normal form for these maps has a simple, Hénon-like form  $(x, y, z) \rightarrow (\alpha + \tau x + z + ax^2 + bxy + cy^2, x, y)$ . We discuss the bifurcations of curves of heteroclinic orbits, defining the primary intersection curves. We relate these to a codimension-one Melnikov function. Numerical experiments will be shown.

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**CP14****Properties of Integrability of Systems in Terms of Transcendental Functions**

Concept of integrability in the class of transcendental functions arises for the reason of availability of this system of asymptotic (attracting or repelling) limited sets, i.e. sets that have the neighborhood which consist of diversities of dimension above 1. Let's remark, that in the spaces of dimension higher than 2 it is eliminated even case of a rough saddle as those can exist whole diversities of a codimension 1 attracted or repelled to the saddle.

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**CP14****Stability Exponents and Separation of Variables**

The problem of defining self-consistent local and global stability exponents is identical to the problem of separation of variables. Near an equilibrium point we show that separation of variables can be performed as a natural extension of the familiar linear system. As in central manifold theory, the decomposition fails for Hamiltonian systems. We explore different options for defining the stability exponents, and the extent of invariance to the initial reference frame choice.

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**CP15****Identification and Characterization of High-Dimensional Chaos**

The restriction of nonlinear time series analysis to low-dimensional chaotic states can be removed with the help of Takens-like theorems for spatially extended systems and delayed systems. With this the experimentally observed high-dimensional chaotic states in spatially extended systems and delayed systems allow for modelling and characterization in terms of invariant measures (Lyapunov exponents, dimensions, entropies). We present the successful application to high-dimensional laser data.

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**CP15****Deterministic Structure in Data from a Free Running Neuronal Ensemble: A Comparison of Non-linear Tests for Determinism**

The search for convincing evidence of determinism in neuronal ensembles is difficult. We compare different strategies for detecting non-linear deterministic structure in inter-burst interval data taken from the rat hippocampal slice preparation. In particular, we used the following tests: 1)a periodic orbit detection algorithm (So et al, Phys.Rev. E, 55 1997), 2)a continuity test (Kaplean, Physica D, 73 1994).

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**CP15**  
**Lyapunov Spectra from Sub-System Information in Spatio-Temporal Systems: a Time-Series Perspective**

We characterise the chaotic behaviour in large spatio-temporal systems by estimating the Lyapunov spectrum from its rescaled counterpart obtained from sub-system information. We discuss a new, more accurate, rescaling technique and its properties. We consider the evolution in tangent space either given explicitly or reconstructed from time-series. We investigate the effects on replacing a large, and potentially infinite, system by a small truncated version with random boundary conditions.

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**CP15**  
**Spatiotemporal Chaos in Yttrium Iron Garnet Films**

The spatiotemporal chaotic behavior of magnetostatic wave states in thin films of Yttrium Iron Garnet is experimentally studied. We use two experimental systems to study the spatial correlation of the chaotic state of the sample. In one experiment, we use two patterned slotline probes to simultaneously measure the magnetic state at two different positions on the sample; in the second experiment we use an optical system consisting of two laser beams to achieve improved resolution.

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**CP15**  
**Low-Dimensional Approximations to High-Dimensional Systems**

Spatially extended, forced, dissipative systems can possess regimes in which they exhibit spatially coherent, low-dimensional behavior. Developing low-order models of such systems that capture the low-dimensional behavior can be challenging. Using numerical GCMs of single and double gyre oceanic circulations as base systems, we compare results from several different Galerkin approaches to constructing low-order systems including projection onto Fourier, EOF, "snapshot", and displacement vector bases. The failure of the EOF approach is related to the EOF's distance from the inertial manifold.

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**CP15**  
**Locating Information Sources in Spatiotemporal Data**

Measures of mutual similarity and coherence can be used to infer the relatedness of signals measured at different locations of a spatially extended evolving system. Clustering techniques can then be used to evaluate the spatiotemporal structure. Such an analysis can for example reveal locations with enhanced information production. The study is motivated by and successfully applied to the location of epileptic foci with grid electrode data.

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**CP16**  
**Period-Doubling Bifurcation Leading to Chaos in an Ecological Model**

A qualitative analysis of a three-dimensional system of ordinary differential equations that model realistic ecological situations, taking into account some essential features of the dynamics of some systems in natural settings is given. Intensive numerical experiments show chaotic transition behavior when some parameters of the system vary according to biological principles. In addition, a perturbed version is studied with regards to certain fluctuations in the environmental conditions which naturally influence ecosystem dynamics.

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**CP16****Nonlinear Stability of Age-dependent Population Dynamics**

Multiple times scale analysis and bifurcation theory are applied to McKendrick's age-dependent population model, where the mortality function is independent of age. A weakly nonlinear analysis produces conditions under which nontrivial equilibrium age distributions lose stability and stable periodic solutions are born. These techniques, applied to the full partial differential equation model, provide information about the population density, unlike methods reducing the model to a system of ordinary differential equations.

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**CP16****Complex Co-evolutionary Dynamics in Simple Ecological Foodwebs**

Quantitative genetic recursion models are a set of integro-difference equations that describes the evolutionary dynamics of populations in which fitness depends on a continuous trait such as body size. These equations are solved using Fast Fourier Transforms and produce bifurcations and complex attractors of both body size and population size in foodwebs of 2 prey and 1 predator. I describe the nature of the attractors as affected by trait hereditability and environmental variability.

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**CP16****Persistence and Extinction in Two Species Reaction-Diffusion Systems with Delays**

Both uniform persistence and global extinction are established for two species predator-prey and competition reaction-diffusion systems with delays in terms of the principal eigenvalues of the scalar elliptic eigenvalue problems by appealing to the theories of abstract persistence, asymptotically autonomous semiflows and monotone dynamical systems.

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**CP16****Urn Models, Replicator Equations and Genetic Drift**

To understand the relative importance of natural selection and genetic drift in the evolutionary process, we study the asymptotic behavior of urn processes via the method of ODE. Of particular interest is the replicator process that represents pair-wise interactions between individuals in a finite population. We show how the limit sets of the replicator process and its averaged ODE (a replicator equation) are related and how genetic drift arises in the replicator process.

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**CP16****Dynamical Behavior of a Discrete, Migration Model with Density-Dependent Selection**

A system of nonlinear difference equations models the effects of selection and migration on a population characterized by two alleles at a single locus. It is shown that a destabilizing bifurcation caused by varying a selection parameter may be reversed by varying a migration parameter. The birth of a chaotic attractor in two dimensions is established as the result of a bifurcation from an invariant line where the dynamics are given by a one-humped chaotic map.

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**CP17****Effect of Noise on Phase Synchronization of Coupled Chaotic Oscillators**

We examine the effect of noise on phase synchronization of coupled chaotic oscillators. It is found that noise can induce phase slips between the oscillators in units of  $2\pi$ . The average time for the oscillators to remain synchronized in phase depends on the noise strength, the scaling behavior of which is investigated. Our results have implications to the observability of phase synchronization in laboratory experiments and this observability is quantified by scaling laws.

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#### **CP17**

#### **From Mode-Locking to Chaos in Integrate-and-Fire Dynamical Systems**

Integrate-and-fire mechanisms are often studied within the context of neural dynamics, although more recently their importance in nonlinear time series analysis has been realised. We show how to construct mode-locked solutions and Arnold tongue structures using recent techniques developed by the authors. The study of chaotic motion is made possible with an extension of the notion of the Liapunov exponent to discontinuous dynamical systems.

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#### **CP17**

#### **Coupled Oscillators near Strong Resonances**

It is well known that two coupled oscillators interact strongly when near a "strong resonance", that is when the ratio of frequencies is the ratio of two small integers. Investigations using normal forms give new insights into the dynamics of weakly coupled nonlinear oscillators, for the strong resonances 1:1, 2:1 and 1:0, near onset. A rich variety of complex dynamics and an application to neural oscillators will be outlined.

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#### **CP17**

#### **Extreme Parametric Uncertainty and Instant Chaos and in Coupled Structural Dynamics**

Nonlinear vibrations occur in linear structures coupled to nonlinear oscillators. Bifurcation to high-dimensional hyperchaos is observed in a driven coupled pendulum-flexible rod system. When the rod is in resonance with the pendulum, the system changes from a low dimensional periodic attractor to a high dimensional chaotic attractor abruptly. It is shown that high dimensional chaotic dynamics is hysteretic, and exhibits extreme sensitivity with respect to small parameter changes

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#### **CP17**

#### **Chaotic Oscillations in the Duffing Oscillator with**

#### **High- and Low-Frequency External Forcing**

In this paper we consider conditions of chaotic oscillations appearance in the Duffing oscillator, when this oscillator is excited with two frequencies, one of which is close to the oscillator natural frequency, and the other is much less than oscillator natural frequency. The comparison of obtained analytically criterion based on the Melnikov technique and numeric modeling results shows good agreement.

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#### **CP17**

#### **Observability of Lag Synchronization of Coupled Chaotic Oscillators**

Lag synchronization is a recently discovered theoretical phenomenon where the dynamical variables of two coupled, nonidentical chaotic oscillators are synchronized with a time delay relative to each other. We investigate experimentally, numerically, and theoretically to what extent lag synchronization can be observed in physical systems where noise is inevitable. Our measurements and analyses suggest that lag synchronization is typically destroyed when noise level is comparable to the amount of average system mismatch. At small noise levels, lag synchronization occurs in an intermittent fashion.

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#### **CP18**

#### **Hopf Bifurcation in Anisotropic Systems**

Hopf bifurcation from group orbits of equilibria in 2D anisotropic PDEs is considered. With periodic boundary conditions imposed, the normal forms following from center bundle reduction are related to those of coupled cells with internal symmetries. For periodic solutions predicted by the equivariant Hopf bifurcation theorem, the dynamics along the group orbit is classified in terms of isotropy subgroups. Without spatial periodicity restrictions, globally coupled amplitude equations involving four wave variables give rise to Benjamin Feir type instabilities.

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**CP18****Pattern Formation in Axial Compressors**

Nonlinear dynamics of evolution equations governing the motion of fluid in jet engine axial compressors is discussed. The nature and stability of travelling wave solutions are investigated. Numerical results are compared with experimental data. Analogies with phase transition problems are pointed out.

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**CP18****Dynamics of Spiral Waves in Weak Inhomogeneity**

The effects of weak inhomogeneity on spiral wave dynamics in the oscillatory regime is discussed within the framework of the two-dimensional complex Ginzburg-Landau equation description. The inhomogeneity gives spatial dependence to the frequency of spiral waves, thus providing a mechanism for one spiral domain to grow and dominate over the other spiral domains. The inhomogeneity also causes spiral vortices to slowly drift with velocities proportional to appropriate gradients of the inhomogeneity.

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**CP18****Scroll Wave Twist in the Presence of Rotational Anisotropy**

Electrical waves in the heart propagate faster along the long axis of the muscle fibers. This axis rotates intramurally across the ventricular wall. We investigate numerically and analytically how scroll wave twist develops in a three-dimensional rectangular geometry as a consequence of this rotating anisotropy. We find the characteristic frequency of the twist is twice that of the unperturbed two-dimensional spiral. We present a phenomenological description of spatial behavior of twist in the linear regime.

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**CP19****Targeting Applying  $\epsilon$ -Bounded Orbit Correction Perturbations**

A low-sized chaotic trajectory is used to compute  $\epsilon$ -bounded orbit correction perturbations in order to rapidly target a trajectory from the vicinity of a starting point to a target. An algorithm that allows fast computation of a set of perturbations to be applied is presented, and its performance is tested in a higher-dimensional system, the kicked double rotor.

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**CP18****Spiral Instabilities in Chemical and Biological Reaction-Diffusion Systems**

Rotating spiral waves can be found in a large variety of chemical and biological systems. For certain parameter values, spirals break up, leading to spatio-temporal chaotic patterns. We investigate this transition using both a simple activator-inhibitor model and a model of propagation of intracellular calcium waves. We perform numerical simulations and stability analysis and find two distinct mechanisms of spiral breakup. They are related to convective and absolute instabilities of periodic planar wavetrains and are characterized by breakup near resp. far away from the center of the spiral.

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**CP19****Double Bracket Energy Sinks and Stabilization of Principal Axis Rotations**

We introduce double bracket energy sinks: a large class of models useful for simulating energy dissipation in quasi-rigid spacecraft systems. We show that double bracket methods can also be applied to nonlinear stabilization of spacecraft minor axis rotations. We then analyze a multi-body system in which the configuration manifold  $Q$  is not equal to the system symmetry group  $G$ . Applying non-

linear control in non-symmetry directions results in stabilization of intermediate axis rotations. The performance of multiple stable layout somersaults by human gymnasts provides the motivation for this work.

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#### **CP19**

##### **Driving Trajectories in Complex Systems**

We present a new paradigm, which combines targeting type of control problem for chaotic systems with the techniques used in system control theory, is proposed. This paradigm is used to rapidly change the evolution of a complex system among desired behaviors. We point out how this paradigm can also be used to nonlinear systems that do not present the characteristics of a complex system.

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#### **CP19**

##### **Micro-Active Control of a Planar Jet**

We present results of a combined experimental and numerical study of the transition to turbulence in a planar jet under the influence of micro-actuators. The jet first becomes unstable to two different kinds of periodic disturbance and we investigate the ability of the micro-actuators to control this low-dimensional behaviour. Thereafter, we consider controlling the mixing properties of the jet through qualitatively different types of disturbance.

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#### **CP19**

##### **Combinatorial Optimization by Piecewise Continuous Dynamical Systems**

A piecewise continuous dynamical system is introduced to solve combinatorial optimization problems like the two dimensional or the mathcal NP hard three dimensional assignment problem. There exists a bijective mapping from the set of feasible solutions to the set of asymptotically stable points of the dynamical system, i.e., the obtained solutions are always feasible. A criterion for global optimality of the obtained solution is given. Part of this is joint

work with M.W. Hirsch.

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#### **CP19**

##### **Quality Factor Control of Lasing Microcavities**

We consider microcavities (1 to 10  $\mu$  in diameter) used as resonators in micro lasers. Ray circulation inside the cavity is modelled by a Hamiltonian map and follows a KAM transition to chaos. At high deformations light circulating inside such a cavity gets emitted by refraction. We present numerical results of controlling the residence time of light inside such a microcavity which is a measure of the quality of light emitted.

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#### **CP20**

##### **Dynamical Systems Methods Applied to Polynomial Factorization Families: A Study of Chaotic Attractors**

This talk will present families of discrete maps that utilize multi-dimensional Newton's method. The advantage is that an attractor is confined to a set of hyperplanes of the phase space. The explicitly defined maps on these hyperplanes can be utilized to predict the dynamics of the chaotic attractor. We have found analytic results on such important topics as attractor characterization, riddled basins, analytic calculation of Lyapunov exponents, topological conjugacies, and invariant measures on attractors.

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#### **CP20**

##### **Pseudo-Riddling in Chaotic Systems**

Previous investigation of the phenomenon of riddling has focused on the case where the dynamical invariant set in the symmetric invariant subspace of the system is an attracting chaotic set. A situation expected to occur commonly in physical systems is that the dynamics in the invariant subspace falls into a periodic window when a system parameter changes. We address whether riddling persists in such a case. In particular, we find that a mixed type of basin structure arises: locally riddled basins and basins of nonzero area. Scaling laws associated with this type of *pseudo-riddled* basin are derived and are supported by numerical experiments.

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**CP20**  
**The Topological Pressure for a Kind of Kicked Integrable Systems**

In the present work, the statistical properties displayed by an integrable system subjected by a chaotic force is studied. This perturbation is an infinite sequence of impulses applied in regular times, with a strength that is taken from a chaotic map. For this model, the topological pressure is exactly computed in the extended phase space, namely system plus perturbation, and its non analyticities are interpreted as dynamical phase transitions on the corresponding Argand plane.

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**CP20**  
**Chaotic Sets Explosions: A Conjecture**

We present a conjecture which puts different global bifurcations, such as crises (sudden changes in chaotic attractors), metamorphoses (sudden changes in basin boundaries), and explosions of chaotic saddles, into the same general setting. We identify a particular configuration of the stable and unstable manifolds (which we call an outer tangency) leading to the birth of new recurrent sets at a finite distance from any previous recurrent set. Numerical examples are presented to illustrate our conjecture.

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**CP20****Life Expectancy Estimations of Transient Chaos**

There are several engineering applications where transient chaos occurs: airplane nose gears, digitally controlled machines, machine tools during cutting, etc. The life expectancy of this behavior is an important parameter for the design work. To avoid extensive simulation work and the corresponding statistical analysis, approximate 1D maps may help to give simple analytical estimation for the life expectancy of chaotic behavior. This method is presented and the conditions of the above approximation are discussed.

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**CP20**  
**Weak Attractors and Basin Riddling**

We introduce the concept of a weak attractor, a somewhat weaker definition of attractor than that suggested by Milnor. We demonstrate that there exists a Milnor attractor associated with the weak attractor and examine some properties of systems with these attractor types. We prove that under certain conditions one may classify the basin type of a Milnor attractor according to its containment within a weak attractor.

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**CP21****Nonlinear Evolution, Filtering, Regularization and Control of Short Wave Instabilities**

We will derive some model equations that arise in the geo-physical context and describe the propagation of long non-linear dispersive waves. We will present numerical schemes to solve these equations and present numerical results that show evidence of local and nonlocal solitary waves in these equations. Theoretical results related to structural stability, existence of perturbed solitary wave and singularity formation will be presented.

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**CP21****Soliton Metamorphosis**

Over the past several years, it has been possible to study the time evolution of a wide class of solitons and other nonlinear structures. New methods have been developed. A number of analytic techniques have also been introduced to study the stability of these structures. Finally, extensive, three dimensional numerical simulations have been performed. These both confirm and augment the analytic results.

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**CP21****The Secret Lives of Kinks**

Coherent structures in spatially extended systems at finite temperature follow stochastic paths. We analyse the stochastic PDE corresponding to  $\phi^4$  field theory in one space dimension. Kinks and antikinks are born in pairs. A pair may remain faithful (diffuse close to and annihilate with its partner) or one member may meet a an unfaithful death.

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**CP21****Travelling Waves in a Model for Water Waves**

We consider the general fifth-order Korteweg-de Vries equation

$$v_t + \gamma v_{yyyy} + \delta v_{yy} - \mu \partial_y \{2vv_{yy} + v_y^2\} + 2\kappa vv_y + 3r^2 v^2 v_y = 0, \quad (0.1)$$

as model for the unidirectional propagation of shallow water waves over a flat surface. For some values of the parameters  $\gamma$ ,  $\delta$ ,  $\mu$ ,  $\kappa$  and  $r$ , the existence of solitary waves of (0.1) has been proved by variational methods. In this paper we have proved the existence of *single bump* solitary waves and *periodic* wave trains described by (0.1) for more general values of the parameters by means of a topological shooting method. We also study qualitative properties of bounded solutions of (0.1) and asymptotic behaviour of the single bump solitary waves of equation (0.1).

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**CP21****Internal Modes and Their Radiation Damping in Vector Solitons of Coupled Nonlinear Schrödinger Equations**

Internal modes of vector solitons and their radiation-induced damping in the coupled nonlinear Schrödinger equations are studied. Bifurcation of internal modes from the integrable systems is analyzed. The region of existence

of internal modes in the parameter space of vector solitons is also determined. In addition, radiation-induced damping of internal modes is investigated. Both exponential and algebraic decays of internal oscillations are revealed.

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**CP21****Multiple Pulses in Dispersive Quadratic Media**

We consider an optics model describing second-harmonic generation and parametric wave interaction in quadratic media. The system consists of two nonlinearly coupled Schrödinger equations, and of particular interest are solitary-wave solutions for which both components are localised in the transverse spatial directions or in time. Applying rigorous methods from homoclinic bifurcation theory, the generation of multibump waves is demonstrated. The stability properties of these multiple pulses are then clarified, also using analytical techniques.

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**CP22****Numerical Continuation of Periodic Orbits in Symmetric Hamiltonian Systems**

Periodic orbits in dissipative systems are generically isolated and can be continued once the phase condition has been taken into account. In Hamiltonian systems periodic orbits are dense and can not be straightforwardly continued. This problem can be overcome by perturbing the system with a dissipative term and treat the periodic orbit as a Hopf Bifurcation at a vanishing value of this extra parameter. If a continuous symmetry is present, we have an additional degeneracy. In this work we propose an integral and a local condition to solve this difficulty and we present results for subharmonic bifurcations in several integrable and non-integrable hamiltonian systems.

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**CP22****Numerical Solutions of a Lienard-type Equation**

The Lienard-type equation The ODE will be transformed into a first order system for which a second-order method

will be developed as a linear combination of first-order methods. The fixed points of the numerical solution ( $B(t) \equiv 0$ ) will be the same as the critical points of the Lienard equation and will have the same stability properties.

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#### **CP22**

#### **The Dynamics of Adaptive Timestepping ODE Solvers**

Many algorithms used to numerically integrate ODEs adaptively change the timestep as the integration progresses while satisfying some local error constraint. We consider a large class of such algorithms, based upon explicit Runge-Kutta methods, and analyze them as (discontinuous) dynamical systems. In particular we present stability results for the numerical methods under various structural assumptions on the ODEs, such as dissipativity, contractivity and gradient structure.

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#### **CP22**

#### **Nonlinear Stability Analysis of Area-Preserving Integrators**

Mathematical theory for the dynamics of area-preserving maps is not in a form that is readily applicable. Beginning with a precise statement of the Moser Twist Theorem and using the theory of normal forms, we obtain a rigorous and fairly complete determination of necessary and sufficient conditions for stability at elliptic equilibria. These conditions are applied to reversible symplectic integrators with special attention to stepsize restrictions for schemes such as leapfrog, implicit midpoint, and Störmer-Cowell.

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#### **CP22**

#### **Using Differential Equation Solvers to Compute the Stable Manifold**

We present an algorithm to compute the (one-dimensional) stable manifold of a differentiable map without using the inverse of the map. We view the stable manifold as locally the solution curve of a differential equation. The vector field is approximated and integrated numerically. After taking an ODE step, a corrector step yields a point on the approximated stable manifold. This method can be used to follow the manifold through the points where  $\det Df = 0$ .

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#### **CP22**

#### **On Computational Aspects of Computer-Assisted Proofs of Chaos in ODE's**

We discuss rigorous numerical methods used in computer-assisted proofs of chaotic behavior for the Lorenz equations by Mischaikow & Mrozek (BAMS'95) and for the Rössler equations by Zgliczyński (Nonlinearity'97). The main numerical problem in such a proof is our inability to obtain reasonable rigorous estimates for Lipschitz constants for the induced flow. This results in 20–60 hours of computer time required to complete the proof. We present a new method, based on the Lohner algorithm, which gives a considerable calculation time reduction (100x).

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#### **CP23**

#### **Mixing in Compressible Flows**

Mixing properties of three-dimensional compressible flows are investigated. The integrability and chaotic advection of these flows is discussed in the spirit of similar theories for incompressible flows. Applications in internal combustion engines are presented. Exit time plots and residence time plots in these flows are discussed and explored in terms of large-scale coherent structures.

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**CP23****Advection of Finite Size Neutral Particles and Control of Hamiltonian Chaos**

Trajectories of finite size neutral particles suspended in 2D incompressible flows separate from fluid trajectories. Given a drag coefficient  $\gamma$ , this separation is stronger in the hyperbolic regions of the base flow. Thus, particles avoid the strongly chaotic regions flows, sticking to fluid trajectories with  $\gamma$ -bound Lyapunoff exponents. Under weak drag, the particles typically settle on KAM fluid trajectories inspiring a numerical scheme to detect KAM surfaces in arbitrary two-degree-of-freedom-Hamiltonian systems.

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**CP23****Passive Tracer Dispersion in Fluids**

In this talk, I will present results on dispersion of double passive tracers, passive tracers with random stopping at various sites, and passive tracers with time-dependent diffusivity. In the last case, the tracer concentration is modeled by a nonlocal advection-diffusion equation.

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**CP23****Transport in Action-Angle-Angle Maps**

The dynamics of a class of three-dimensional volume-preserving maps - the so-called action-action-angle maps - is discussed. A mechanism for transport found by Piro and Feingold is investigated rigorously in the perturbative set-up. A persistence theorem for periodic orbits is proven using an analogue of subharmonic Melnikov theory. A non-persistence theorem for a class of two-dimensional invariant manifolds is proven. These two results are used to show that transport involves a creation of a pair of hyperbolic fixed points close to a manifold on which a resonance condition is satisfied. Using this mechanism, a fast transport is achieved through a large portion of the phase space. Applications to three-dimensional perturbations of shear flows are presented.

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**CP23****Matrix Approaches to Mixing Rates**

It is often interesting to know how quickly a given dynamical system mixes to its natural invariant measure. This rate is given by the second largest eigenvalue of an associated transfer operator. Recent results by Keller and others suggest that Ulam-type matrix approximations may yield good spectral information in this setting. This talk will discuss the application of a trace formula based scheme to Ulam approximate matrices to compute mixing rates for various systems.

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**CP23****Frequency Dependence of Chaotic Transport in the Presence of Diffusion**

We study the combined effects of chaotic advection and molecular diffusion on a region of pollutant in simple, time periodic recirculating flows. We find that the flux function and the width of the stochastic zone in the non-diffusive systems have a universal frequency dependence. Furthermore, these systems have a universal adiabatic transport mechanism. These universal forms imply, as we demonstrate numerically, that diffusive, low frequency (*high frequency*) stirring leads to efficient transport on shorter (*longer*) time scales.

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**CP24****Elliptic Problems on Domains with Rapidly Oscillating Boundaries**

We consider elliptic boundary value problems subject to Robin (third type) boundary conditions on domains with rapidly oscillating boundaries. We ask what the limiting problem is as the oscillations get faster and faster and the domain approaches a smooth domain. In some cases we get a Robin problem with a different coefficient on the boundary, in other cases the Dirichlet problem.

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**CP24****Continuation of Solutions to 1D and 2D Nonlinear Elliptic PDEs by the Multiquadric Method**

The Multiquadric Radial Basis Function (MQ) Method is a collocation method with global basis functions. It is known to have exponential convergence for interpolation problems. We discretize nonlinear elliptic PDEs by the MQ method. This results in modest size systems of nonlinear algebraic equations which can be efficiently continued by standard continuation software such as AUTO. Examples are given of 1D and 2D PDEs. For these examples, the accuracy of detected bifurcation and the number of unknowns compare favourably with known results from the literature

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**CP24**  
**On the Vibrations of a Plate-Beam Structure**

We consider the transversal deflections which may be large, of a dynamically- coupled Von Karman system consisting of a plate which has a beam attached to its one edge. The deflections of the coupled system is described by the non-linear Von Karman system together with the beam equation, which is, however, compounded by the interaction of the beam and the plate. The problem is considered in the form of a non-linear evolution problem in a product space. We show the existence of a unique local solution by following a fractional powers approach to first construct a "weak" solution in a larger space. Regularity properties for this solution yield a unique local strong solution for the original boundary-value problem. This approach entails the introduction of fractional powers of a pair of matrices.

Prof. Marié Grobbelaar  
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**CP24**  
**Asymptotic Analysis of a Spike-Type Solution of an Elliptic Equation**

The boundary function method is used for construction of a spike-type solution of an elliptic equation in which nonlinear term depends on spatial variables. Under certain conditions the method allows to define the position of a spike without using exponential asymptotics.

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**CP24****On the Multiplicity of Solutions of Two Nonlocal Variational Problems**

In this joint work with Juncheng Wei, I study two nonlocal variational problems. One models micro-phase separation of diblock copolymers and the other models solid-solid phase transformations that lead to fine structures. I consider a parameter range where the problems can be approximated by their asymptotic limits. All the local minimum solutions of the limiting problems are found. Because these local minima are isolated, and hence stable under perturbation, near them there exist local minimum solutions of the original problems.

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**CP24****Global Attractors for a Degenerate Equation from Viscoelasticity**

We study a parabolic-hyperbolic partial differential equation modelling the forced longitudinal motions of a light nonlinearly viscoelastic rod attached to a heavy particle. Applying phase-plane methods to this infinite-dimensional problem, we prove that the equations have a global attractor. This attractor is contained in an inertial manifold on which the dynamics is governed by the classical ordinary differential equation describing the motion of the particle when the rod is massless.

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**CP25****Dynamical Aspects of System Identification**

System identification means using the inputs and outputs of a system to determine a model that can reproduce its behavior. Often this can be done by observing an auxiliary dynamical system that takes the measured output of the original system as input. This talk examines this problem for the class of coupled oscillator systems. Issues addressed include performance criteria of the identifier and the effect of structural properties such as symmetry in the original system.

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**CP25****Error Statistics, Model Selection and Confidence**

**in Chaotic Time-Series Prediction**

The traditional approach to time-series embedding prediction has been by pointwise (usually linear) regression of the  $k$ -nearest neighbors, assuming a good embedding, and additive noise. With a finite data set, there is an inherent conflict between balancing the noise fluctuations of a small  $k$ , and large  $k$  data needs of fitting many parameters of large  $d$ . We develop tools to 1) select the statistically significant model for fixed  $k$ , 2) select the best  $k$  and model to optimize the resultant prediction, in the sense of having the smallest confidence bands for a fixed level of confidence.

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**CP25****Symbolic Sequence Approach to Biological Oscillator Dynamics**

Symbolic dynamics partitions phase space so that information about the underlying orbital skeleton is captured by the partitions, even in systems where noise precludes a generating partition. Analysis of the resulting symbol sequence statistics can show local dynamics including bifurcation behavior, as well as recurrence within and coupling between time series. We use a novel approach to symbolic analysis to characterize dynamics in systems of coupled biological oscillators.

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**CP25****Interspike Interval Embedding Theorem**

We give the proof of the Interspike Interval Embedding Theorem conjectured by T. Sauer, which applies to the data consisting of series of event timings. The theorem states that we do not lose any topological information through embedding process under some assumptions. The proof assumes that the event timings are created through so-called the "integrate-and-fire" model. We also consider the extension to the cases where the magnitude of the events are available.

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**CP25****Sunspot Cycle: A Driven Nonlinear Oscillator?**

A property of nonlinear oscillators – mutual dependence between their instantaneous amplitude and frequency is tested in the sunspot data using the surrogate data technique. The instantaneous amplitudes and frequencies are obtained by means of the analytic signal approach. In several tests the amplitude-frequency correlation has been found significant on levels ranging from  $p < 0.03$  to  $p < 0.07$ , which supports the hypothesis of a driven nonlinear oscillator as a mechanism underlying the sunspot cycle.

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**CP25****An Application of Computational Topology to Dynamical Systems**

We present computational techniques that detect bifurcations in the topology of invariant sets. A familiar example comes from 2-d area-preserving twist maps. Invariant circles trap chaotic orbits and imply some degree of stability that is destroyed when the nonlinearity is increased. Analogous structures in higher-dimensional maps are difficult to visualise so computational tools are necessary to give quantitative information about their topology. In particular, we characterise how the number of components and number of holes vary with a resolution parameter.

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**CP26****Adaptive Mesh Refinement for Simulating Excitable Media**

Using an adaptive mesh refinement (AMR) method for hyperbolic equations formulated on hierarchical Cartesian meshes [1], we have investigated the accuracy, efficiency, and utility of AMR for simulating two- and three-dimensional excitable media, whose dynamics consist of propagating fronts with fast rise times and large spatial gradients. We summarize results for the Barkley and Luo-Rudy I models and discuss how the efficiency of AMR is related to the geometric structure of the fronts. [1] M. J.

Berger and P. Colella, *J. Comp. Phys.* 82, 64 (1989).

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**CP26****Geometric Analysis of Population Rhythms in Neuronal Network Models with Fast Inhibitory Synapses**

Geometric dynamical systems techniques yield insight into population rhythms, such as synchrony and clustering, in models of coupled neurons. Such analysis elucidates general mechanisms by which firing patterns arise and demonstrates how cells' intrinsic and synaptic properties shape network behavior. We employ this approach for models, based on the Hodgkin-Huxley formalism, relevant to thalamic activity during sleep and paroxysmal discharges. A key finding is that models with different complexity levels support qualitatively different synchronization mechanisms.

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**CP26****The Viscous Nonlinear Dynamics of Twist and Writhe**

Exploiting the "natural" frame, we formulate the intrinsic dynamics of twisted elastic filaments in viscous flow, in

which coupled nonlinear equations describe the interplay of curvature and twist. These equations are used to illustrate *geometric untwisting* of open filaments, whereby twisting strains relax through a transient writhing instability without axial rotation. Experimentally-observed writhing motions in *Bacillus subtilis* fibers [ Mendelson et al., *Journal of Bacteriology* 177, 7060 (1995)] may be examples of this process.

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**CP26****Chaos and Self-Organization in the Three-Letter Code Heteropolymer Model**

Analysis of the radius of gyration, potential and kinetic energies obtained by Langevin molecular dynamics simulation of the three-letter code heteropolymer model indicates that the motion of typical  $\alpha$ -helix and  $\beta$ -sheet structures is chaotic. Comparison between simulations at different temperatures shows that the folding process can be described as the typical behaviour of a dissipative system going to an attractor. The implications and new insight on how to analyse protein folding are discussed.

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**CP27****Bifurcation Analysis of Spontaneous Symmetry-Breaking in Circular Josephson Junction Arrays**

We use equivariant bifurcation theory to investigate subharmonic instabilities of the synchronous periodic state of circular arrays of  $N$  identical Josephson junctions. This instability gives rise to period-doubled solution branches, which when stable lead to a step in the  $I - V$  curve. We determine existence and stability of the period-doubled solution branches as functions of the system parameters. For  $N = 4, 9$ , we determine the qualitatively distinct  $I - V$  curves over a range of parameters, and present numerical evidence supporting our results.

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**CP27****Dynamics of Continuous-Time Boolean Networks and Parkinsonian Tremor**

Analysis of continuous-time, binary-response networks allows us to relate network structures to dynamical behaviours. The form of an underlying discrete (fractional-linear) mapping encodes information on existence, stability and exact periods of periodic orbits. In specific cases aperiodic behaviour can be proven and its properties investigated. Global transitions from aperiodic to periodic regimes often result from local weakening of connections and are suggested as the mechanism behind tremor in Parkinson's disease.

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**CP27****Spatiotemporal Organization in Long Chains of Chaotic Oscillators with Impurities**

We investigate the influence of impurities introduced into lattices of coupled identical damped driven chaotic pendula and chaotic maps. Contrary to our expectations, a single impurity can control the chaotic behavior of a long array of chaotic oscillators and induce spatiotemporal organization. A spatial pattern emerges that is robust to variations in coupling strength and the length of the impurity pendulum. In addition, this effect appears to be independent of the size of the chain. A possible mechanism responsible for this phenomenon will be discussed.

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**CP27****Instabilities and Discrete Rotating Waves in Coupled Chaotic Oscillators**

We present results on chaotic oscillators that are linearly coupled by using periodic and free-end boundary conditions. The systems are characterized through a linear stability analysis applied to the homogeneous chaotic state. This kind of analysis unveils the appearance of instabilities, that yield different discrete spatio-temporal structures, that in many cases can be analyzed from the pat-

tern of the bifurcation associated to the instability. These structures include those obtained from the so-called fast bifurcations.

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**CP27****Synchronization in Arrays of Oscillators with Different Natural Frequencies**

Arrays of oscillators whose natural frequencies increase linearly along the array are interesting in terms of different applications. For example, they can model the vortex shedding in a flow past cone-shaped bodies, peristaltic phenomena in mammalian small intestine and generation of cardiac rhythm in sinoatrial node. We study how small additions to the linear trend of natural frequencies and external forcing modify synchronous dynamics of arrays consisting of quasiharmonic or relaxational oscillators, thus providing possible ways to control such systems.

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**CP27****Time Delay in the Kuramoto Model of Coupled Oscillators**

We generalize the Kuramoto model of coupled phase oscillators to allow time-delayed interactions. New phenomena include bistability between synchronized and incoherent states, and unsteady solutions with time-dependent order parameters. We derive exact formulas for the stability boundaries of the incoherent and synchronized states as a function of the delay. The experimental implications of the model are discussed for populations of chirping crickets and for physical systems such as coupled phase-locked loops or lasers.

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**CP28****Localized Traveling Waves Under the Influence of Temporal Modulation: Growing Worms and Pulses**

Motivated by the observation of localized waves in binary-mixture convection ('pulses') and in electroconvection in nematics ('worms'), we investigate within coupled

Ginzburg-Landau equations their response to a temporally periodic modulation. Over a wide range of parameters their localization is due to a coupling to an additional slow mode. The modulation directly affects the speed of the localized waves. Due to the coupling to the additional mode, the change in speed strongly impacts their size.

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#### **CP28**

#### **Multi-Phase Patterns in Periodically Forced Oscillatory Systems**

Periodic forcing of an oscillatory system produces frequency locking bands within which the system frequency is rationally related to the forcing frequency. In spatially extended systems patterns form consisting of fronts separating the different phase-locked states. I will describe an instability of these fronts that causes a transition from stationary two-phase patterns to traveling  $n$ -phase patterns. This instability leads to, for example, the collapse of a four-phase spiral wave into a stationary two-phase pattern as the forcing strength within the 4:1 resonance is increased.

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#### **CP28**

#### **Oscillatory Patterns in a Model of Autocatalytic Surface Reaction**

A reaction-diffusion-equation for a mobile adsorbed CO-species is coupled with a system of three ordinary differential equations for adsorbed oxygen, a nonreconstructed catalytically active platinum surface, and subsurface oxygen. The latter functions as a memory for the active surface, that shows hysteresis in its phase transition. Bifurcation analysis finds critical parameters where changes in the qualitative behavior serve as a method to verify the mathematical model. Simulations of oscillatory patterns

are compared to experimental observations.

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#### **CP28**

#### **$D_4$ -Equivariant Maps and the Takens-Bogdanov Bifurcation**

In many double-diffusive convection problems, a Takens-Bogdanov (TB) bifurcation, at which primary Hopf and pitchfork bifurcations coincide, plays a major role in organising local and global bifurcations at nearby parameter values. The analysis of the TB bifurcation in two-dimensional convection has largely been completed, but the corresponding three-dimensional problem presents additional difficulties, particularly near the global bifurcations. I consider one case with  $D_4$  symmetry in which the dynamics near the global bifurcation can be described by a generalisation of the well-known Lorenz map.

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#### **CP28**

#### **Parametrically Excited Surface Waves: Normal Form Symmetries and Pattern Selection**

Motivated by experiments on exotic standing wave patterns in the two-frequency Faraday experiment, we investigate the role of normal form symmetries in the pattern selection process. We focus on the situation where the trivial state loses stability simultaneously to harmonic and subharmonic waves of different wavenumbers. We show that the case where the harmonic waves have a longer wavelength than the subharmonic waves is markedly different from the case where the harmonic waves have a shorter wavelength.

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#### **CP28**

#### **Travelling Front Solutions arising in a Chemotaxis-Growth Model**

We consider a bistable reaction-diffusion-advection system describing the growth of biological individuals which move by diffusion and chemotaxis. To concern with the stability of envelope of growth patterns, we first prove the transversal stability of flat travelling front solution inside long channels. Numerical simulations show transitions from stable flat travelling front to spreading turbulence as the chemotaxis effect is stronger. The destabilized patterns evolve

into complex ones with network-like structures.

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### CP29

#### Feedback Linearization of Unstable Rolling Phenomenon

We present several models of nonholonomic mechanical systems which exhibit unstable rolling characteristics (called shimmy) and their associated dynamics. The difference between the models relates to the relative sophistication of modeling the contact between a tire and the surface upon which it rolls. Feedback linearization is a standard nonlinear controller wherein a global nonlinear change of coordinates is constructed in which the control system is rendered linear. Unfortunately, this design technique applies only to a limited set of problems; however, this feature appears to be generic for the shimmy problems we consider. We present the simple application of this technique to the example shimmy problems and the geometric reason for its apparent general applicability.

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### CP29

#### Dynamic Model Reduction

The subject of model reduction addresses the need for low order approximations of large systems of differential equations. This need is especially important in control theory, where efficiency is key. A dynamical-systems-based approach to model reduction will be presented. The ideas originate from the nonlinear Galerkin methods from fluid dynamics. These methods have a natural extension to a model reduction setting. A new method will be derived, with analytic and numerical results.

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### CP29

#### Swimming Dynamics of a Shape-Changing Object

The swim of a 2D object propelled by constant change of contour is studied. The coupled rigid-body/fluid dynamics is formulated into a system of integro-differential equations. Even when propelled by periodic and unintelligent swimming contours, chaotic trajectories are predicted.

Prescribed trajectory can be pursued through varying the driving contours. The dynamics of a falling paper and Sky Surfing are discussed in connection to the present system based on the same equations.

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### CP29

#### Control of Distributed Autonomous Robotic Systems with underlying Task Assignment

We propose an error resistant control mechanism for distributed autonomous robotic units to navigate in an environment with obstacles where the robotic units have to be assigned to manufacturing targets in a cost effective way. Our dynamical systems approach allows self-organized control of these robots. The system's equations are based on the selection behavior known in pattern formation of physical, chemical and biological systems, and a Behavioral Forces model for pedestrian crowds.

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### CP29

#### Finite-Dimensional Control of a Nonlinear Distributed Parameter System

We address the problem of regulating a dissipative PDE that models a reaction-diffusion process. A nonlinear model reduction method was employed to approximate the long-term behavior of the PDE dynamics by a dynamical system of finite, small dimension. Closing the obtained system with a linear controller effectively stabilizes the PDE truncation(s) locally; this does not, however, exploit the fully nonlinear reduced model. On the other hand, nonlinear, feedback linearizing control results in large control spillover to the residual modes. We design an inverse optimal control law and demonstrate its robustness with respect to fast unmodeled dynamics. Simulation results demonstrate the performance advantages of the inverse optimal control law over the linear quadratic regulator in stabilizing models derived from our illustrative example.

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**CP29**  
**Control and Tracking in the Diamagnetic Kepler Problem**

We have studied the system of a charged particle in the presence of two competing potentials, the Coulomb field and an external magnetic field. The resulting nonlinear system has a quantal analog (the Diamagnetic Kepler problem(DKP))and has been fundamental in classical and quantal studies of chaos and its characterisation. We have achieved *control* and *tracking* of a number of classical unstable periodic orbits in various regimes of scaled energy and magnetic strength. The DKP Hamiltonian displays a very rich and complex dynamics that has created a number of difficulties for the application of standard control algorithms. Our solutions to these problems will be discussed. Furthermore, our tracking procedure allows us to follow the unstable periodic orbits for increasing scaled energy (for fixed scaled magnetic field) as the system evolves from a (almost) regular, to a mixed and finally, to a fully chaotic regime.

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**CP30**  
**The Breakdown of Shadowing in a Typical Physical System**

The sinusoidally forced, damped, double pendulum is presented as a simple paradigm system that is unshadowable due to the presence in the attractor of periodic orbits that have different numbers of unstable directions. An argument is provided for the existence of parameter values where shadowing fails. Numerical simulations show attractors containing fixed points with different numbers of unstable directions. Finite-time Lyapunov exponents whose signs fluctuate, the hallmark of unshadowable systems, are also observed.

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**CP30**  
**Transition To High-Dimensional Chaos**

High-dimensional chaotic systems are systems with more than one positive Lyapunov exponent. We investigate how high-dimensional chaos can arise when a system parameter changes. A route is identified whereby a subsystem undergoes a cascade of period-doubling bifurcations to low-dimensional chaos, after which the complementary subsystem becomes chaotic, leading to an additional positive Lyapunov exponent for the whole system. A characteristic feature of this route is that the second largest Lyapunov exponent passes through zero smoothly. Four examples are presented: a discrete-time map, a continuous-time flow, the double rotor map, and a population model for species dispersal in evolutionary ecology.

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**CP30**  
**Metamorphosis of Chaotic Saddle**

Chaotic saddles are nonattracting dynamical invariant sets that can lead to a variety of physical phenomena. We report our finding and analysis of a type of discontinuous global bifurcation (metamorphosis) of chaotic saddle that occurs in high-dimensional chaotic systems with an invariant manifold. A metamorphosis occurs when a chaotic saddle, lying in the manifold, loses stability with respect to perturbations transverse to the invariant manifold. The fractal dimension of the chaotic saddle increases *abruptly* through the bifurcation. We illustrate our finding by using a system of coupled maps.

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**CP30****Box Dynamics**

We study maps in  $\mathbb{R}^2$  by placing a grid on the region of interest and finding all the gridboxes containing the image of each gridbox. Our technique determines the image of the *entire* box up to machine accuracy. We use graph theory algorithms to locate possible periodic orbits. With successive refinements, as small as  $10^{-15}$ , we can verify that trajectories exist. Unlike work of Dellnitz and of Mischaikow, our method can find optimal trajectories.

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**CP30****High-Quality Numerical Shadowing for Differential Equations**

We present an algorithm for finding an orbit of a given chaotic dynamical model that shadows a given time series. The algorithm is applied, using as the given model a scheme for integrating the Lorenz equations. We demonstrate agreement of the resulting orbit with the equations of the dynamical model to within machine double precision for time series as long as  $10^5$  samples, corresponding to 100 Lyapunov times.

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**CP30****Spurious Lyapunov Exponents Computed Using the Eckmann-Ruelle Procedure**

Numerically computing Lyapunov exponents of a dynamical system from a time series of measurements produces spurious exponents. We examine the Eckmann-Ruelle procedure and determine explicit formulas for the computed exponents (true and spurious) in the low noise limit. For example, if one generically embeds a one-dimensional system with exponent  $h$  into  $m$ -dimensional space, the computed exponents will be  $h, 2h, \dots, mh$ . Formulas for higher-dimensional cases will also be discussed.

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**CP31****Large Discrete Breather Dynamics in the Presence of a Phonon Bath**

The dynamics of the discrete nonlinear Schrödinger lattice initialized in a non-extensive manner is studied. The non-extensivity causes the system to stay in a non-equilibrium state for a very long transitory period of time where standard Boltzmann statistics is inappropriate. Alternative

statistics based on a non-standard entropy concepts (such as *Tsallis entropy*) should be applied. Our study of the nonlinear system locked in this *meta-thermodynamic* state focuses on the dynamics of discrete breathers.

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**CP31****Solitonic Excitations on Lattice Systems**

The behavior of continuum solitonic excitations is well-understood. However, many interesting applications of soliton-exhibiting model systems (DNA, Josephson junction arrays or material dislocations) are inherently discrete. We will outline the radical modifications that discreteness entails (radiation effects, shape modes bifurcating from the essential spectrum, pinning, to name a few) and will attempt to explain via analytical (Evans functions, collective variable theories) and computational means these complex and exciting new phenomena.

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**CP31****Global Boundary Stabilization of the Korteweg-de Vries-Burgers Equation**

The problem of global exponential stabilization by boundary feedback for the Korteweg-de Vries-Burgers equation on the domain  $[0, 1]$  is considered. We derive a control law of the form  $u(0) = u_x(1) = u_{xx}(1) - k[u(1)^3 + u(1)] = 0$ , where  $k$  is a sufficiently large positive constant, and prove that it guarantees  $L^2$ -global exponential stability,  $H^1$ -global asymptotic stability, and  $H^1$ -semiglobal exponential stability. The closed-loop system is shown to be well posed.

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**CP31****Approximate Group Theoretic Laws for Self-focusing and Solitons**

The group theoretic laws for paraxial self-focusing in cylindrical geometry and solitons governed by the nonlinear wave-equation are presented. The paraxial quasi-optic equation gives in this case the nonlinear Schrödinger equation solutions close to the exact solution but in a reduced regime of application. The dynamics of the width-eikonal are studied in this context using the the restricted Lorentz group, equivalent to the ABCD laws of gaussian beam propagation.

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### CP31

#### Radiation Loss of Dispersion-Managed Solitons in Optical Fibers

Dispersion-managed optical fibers have been used to transmit soliton-like pulses that breathe as they propagate. Here, based upon the nonlinear Schrödinger equation with a periodic dispersion coefficient, we identify an intrinsic resonance mechanism causing such dispersion-managed ‘solitons’ to radiate and thus lose energy continuously. In the short dispersion-map period limit, the radiation loss is exponentially small and is calculated by using techniques of asymptotics beyond all orders.

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### CP31

#### Periodic Solutions of Nonlinear Schrodinger Equation in the Strong Dispersion Management Regime

The technique of dispersion management for pulse propagation in telecommunication lines has been a subject of intensive theoretical, experimental, and numerical investigations in the last few years. The existence of a pulse which nearly resumes its shape after many periods of dispersion management has been shown numerically and confirmed by approximate analytic techniques. We prove that there exists a solution close to a periodic solution of the linear system for a long time.

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### CP32

#### Unconditionally Gradient Stable Time Marching the Cahn-Hilliard Equation

Numerical methods for time stepping the Cahn-Hilliard equation are given and discussed. The methods are unconditionally gradient stable, and are uniquely solvable for all time steps. The schemes require the solution of ill-conditioned linear equations, and numerical methods to accurately solve these equations are also discussed.

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### CP32

#### The Effects of Collocation Methods on Local Bifurcations of Flows

The common local bifurcations of scalar flows are transformed here under a class of algorithms known as linearized one-point collocation methods. Through normal forms, it

is shown that each such bifurcation gives rise to an exactly corresponding one in its discretization. The conditions for spurious period doubling are derived. A singular set induced by the methods has behavioral consequences, including loss of monotonicity of solutions, intermittency, and attractor basin distortion.

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### CP32

#### Robust Newton-Picard Methods for Bifurcation Analysis of Periodic Solutions of Partial Differential Equations

In this presentation, we will present some recent robustness-increasing enhancements which we have made to our single- and multiple shooting based Newton-Picard methods. By monitoring the convergence behavior, we have dramatically reduced the failure rate of the iterative solver. We will demonstrate these improvements with some test results. A free implementation of the algorithms is available.

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### CP32

#### Finite Difference Approximations of Delay Differential Control Systems

This paper deals with optimal control problems for dynamical systems governed by differential inclusions with time delays. We develop a finite difference method for efficient approximations of such problems by optimal control problems with discrete time. Under general assumptions we establish well-posedness of discrete approximations that ensures a strong convergence of optimal solutions. Finally we apply this method and appropriate tools of variational analysis to obtain new necessary optimality conditions for control problems under consideration.

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### CP32

#### A Dynamical System Associated with Newtown's Method for Parametric Approximations of Convex Minimization Problems

We study the existence and asymptotic convergence when  $t \rightarrow +\infty$  for the trajectories generated by

$$\nabla^2 f(u(t), \epsilon(t))\dot{u}(t) + \dot{\epsilon}(t) \frac{\partial^2 f}{\partial \epsilon \partial x}(u(t), \epsilon(t)) + \nabla f(u(t), \epsilon(t)) = 0$$

where  $\{f(\cdot, \epsilon)\}_{\epsilon > 0}$  is a parametric family of convex functions which approximates a given convex function  $f$  we want to minimize, and  $\epsilon(t)$  is a parametrization such that

$\epsilon(t) \rightarrow 0$  when  $t \rightarrow +\infty$ . This method is obtained from the following variational characterization of Newton's method ( $P_t^\epsilon$ )

$$u(t) \in \operatorname{argmin}\{f(x, \epsilon(t)) - e^{-t}\langle \nabla f(u_0, \epsilon_0), x \rangle : x \in H\}$$

where  $H$  is a real Hilbert space. We find conditions on the approximating family  $f(\cdot, \epsilon)$  and the parametrization  $\epsilon(t)$  to ensure the norm convergence of the solution trajectories  $u(t)$  towards a particular minimizer of  $f$ . The asymptotic estimates obtained allow us to study the rate of convergence as well. The results are illustrated through some applications to barrier and penalty methods for linear programming, and to viscosity methods for an abstract non-coercive variational problem. Comparisons with the steepest descent method are also provided.

This work was partially supported by Fondecyt 1961131. The work of J. M. Pérez C. was supported by funds from Fundación Andes.

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#### **CP33**

##### **Lagrangian Diffusion in Chaotic Fluid Flows**

Bidimensional turbulence is simulated by considering passively convected scalar gradients in chaotic fluid flows for a given spatially smooth velocity field. For periodic impulsive perturbations in the velocity, fluid flows are described by the standard map with a random phase. Anomalous diffusion processes associated with this map and their dependence on the control parameters are investigated. There is a competition between the enhancement of the diffusion coefficient, caused by accelerator modes, and its decrease due to the random phase.

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#### **CP32**

##### **Numerical Computation of Solitons and Waves Using Adaptive Moving Grids**

We present a sophisticated numerical method for approximating solutions of higher-order PDE models. These types of PDE models, such as the KdV-equation, or suspension-bridge models, possess solutions with high spatial gradients that also move in time, for example as a soliton or as a wave. It is well-known that traditional methods on uniform meshes may have severe problems with efficiently and accurately computing numerical approximations. For this purpose, a special numerical method has been developed: a so-called adaptive moving grid method. Successful application of the method is shown for PDEs from different application areas.

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#### **CP33**

##### **Slow Diffusion and Effective Stability of Dust Particles Orbiting Asteroids**

Inspired by several planned space mission aimed at asteroid exploration, we study the dynamics of dust particles orbiting asteroids. Particular emphasis is placed on the diffusive motion in a neighborhood of linearly neutral, periodic orbits corresponding to tightly bound orbits about the asteroid. Through a Hamiltonian normal-form computation, we derive Nekhoroshev-type estimates that yield regions of effective stability, i.e., where the grains would remain for times exceeding the age of the solar system.

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#### **CP33**

##### **Power Spectrum of Passive Scalars in Two Dimensional Chaotic Flows**

We theoretically study the power spectrum of passive scalars being transported in two dimensional chaotic flows. Using a wave-packet method introduced by Antonsen et al., we numerically investigate several model flows, and confirm that the power spectrum has the  $k^{-1}$ -scaling, which was predicted by Batchelor but questioned by Williams et al. recently. On the other hand, we observe that the power spectrum has smoother roll-off than what is predicted by Batchelor. We find that disagreement is due to strong intermittency of stretching in the model flows.

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#### **CP33**

##### **Turbulent Transport by Waves**

We consider the *transport of a passive scalar* (like pollutant concentration, temperature, or dye concentration) in a prescribed velocity field which is a superposition of waves. The spreading of an oil spill on the ocean surface can serve as an example. We find an equation for the averaged concentration of the passive scalar. Besides the usual diffusion term, with a second derivative, this equation contains the dispersive term, with a third derivative. The formulas for the coefficients of turbulent diffusion and turbulent dispersion are derived. Both of them have the fourth order with respect to wave amplitudes.

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**CP34****Mean Curvature Laws for Spreading Solid Films**

An asymptotic treatment of solid films freezing onto undercooled substrates is developed. Contact conditions select the speed at which films advance; for rapidly spreading films these conditions may be applied directly to the asymptotic equations describing the film even though the underlying approximation is invalid at the contact line. Selected velocities are determined analytically in a secondary limit where laws of motion by mean curvature are derived describing the evolution of arbitrarily shaped contact lines.

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**CP34****Optimal Gap Conditions for Invariant Manifolds**

We give gap conditions for the existence of invariant manifolds for systems of semilinear differential equations in Banach Space. These conditions involve the growth bounds for the semigroups corresponding to the linear part of the equations and the Lipschitz constants of the nonlinear parts. These results are optimal for finite systems of equations, and can be extended to infinite systems and linear skew-product flows.

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**CP34****Slow Manifolds and Inertial Manifolds in the Maxwell-Bloch Equations**

We present examples of slow manifolds arising from two singularly perturbed PDE from laser physics. These manifolds contain the asymptotic dynamics of the system and lead to a good understanding of the global dynamics and the structure of the attractor. Mathematically, it is a demonstration of the methods of geometric singular perturbation theory in infinite dimensions. We shall indicate connections of our work to recent persistence theorems of Bates *et al* for semiflows.

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**CP34****On the Stabilization of Bounded Solutions for Parabolic Systems with Analytic Nonlinearity and Liapunov Functional**

We consider the boundary value problem for nonlinear parabolic systems with analytic nonlinearity and Liapunov functional. A solution of this problem is stabilized if the set of all partial limits of infinity consists of a unique stationary solution. We prove that every uniformly bounded solution of the problem stabilizes. If a solution is defined and uniformly bounded for negative time, it is shown that the solution stabilizes in backward time. Therefore, the global attractor of this problem consists of a stationary solution and of connected orbits. Moreover, flow on global attractor is a gradient-like flow.

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**CP34****Structural Analysis of Incompressible Flows**

I shall present a joint work with T. Ma on structural analysis of 2D incompressible flows. Topics include 1). structural classification, structural and block stability, and structural bifurcation of both divergence-free vector fields and solutions of Euler or Navier-Stokes equations, and 2). applications to the structure analysis of a wind-driven, double gyre, quasi-geostrophic ocean model, which is based on a joint paper with J. Shen and T. Tachim Medjo.

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**CP35****Prediction and Noise Filtering in Dynamical Systems: A Neural Network Approach**

The modeling of chaotic time series with neural networks has mainly been concerned with the development of architectures and learning paradigms that minimize the prediction error. On the other hand, a characterization of chaos in the framework of information theory provides a powerful statistical description that captures the essence of chaos by taking into account not only the short term prediction but the full evolution of uncertainty in terms of the *information flow*. In this contribution, we combine both strategies in order to extract the deterministic part of noisy chaotic systems. The noise filtering is obtained as the result of a neural network model selection based on a surrogate statistical test. In fact, the test selects a neural network deterministic model distorted with an estimated model of the noise which together show the same transmission of information in the future as in the original data. The methodology will be highlighted by several examples to assess its usefulness in the dynamical analysis of complex

(e.g. neurophysiological) systems.

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**CP35**

**Tracking Doppler-Shifted Chaotic Waveforms**

The idea of using chaotic waveforms in radar applications introduces the problem of tracking Doppler information contained in the received signal. In this paper, a model is presented for generating Doppler-shifted chaotic waveforms and a tracker is described capable of on-line estimation of the frequency shift. The tracker employs a response system containing a parameter that is controlled to simultaneously achieve synchronization and convergence of the parameter to the Doppler shift.

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**CP35**

**Nonlinear Dynamic Signal Processing of Chaotic Noise in a Real Channel**

This paper considers the use of nonlinear dynamic forecasting as a signal processing tool to remove background noise from a real channel. The examples include controlled experiments where the background noise is computer generated chaos obscuring speech signals in the room, as well as an experiment where the background noise was generated by a vibrating warehouse air handler system. Signal-to-noise ratio improvements and channel effects on the chaos will be discussed.

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**CP35**

**The AWARE (Advanced Warning Against Runaway Events) Project**

A device based on state space reconstruction from temperature measurements have been developed to detect in advance, for countermeasures be taken, the initiation of a runaway -thermal excursion of the reaction mass- in batch reactors. The development of the early warning detection criteria, based on an invariant property of the system, as well as the simulated and experimental verification in a small scale pilot reactor using an acid catalyzed esterification reaction are presented.

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**CP35**

**Modeling of Large Scale Complex Adaptive Systems**

The paper describes modeling techniques used to simulate and forecast demand for products, purchasing of which, is determined by social behavior more than by price (e.g., music CDs, movie tickets). We describe the methodology of Complex Adaptive Systems (CAS) that analyses dynamics of systems composed of large numbers of interacting individuals. We illustrate discussed concepts with simulation framework IceCore<sup>?</sup> created by ESG of PricewaterhouseCoopers LLP to design, simulate, and analyze large-scale CAS. We give examples of real life applications and numerical results illustrating advantages of CAS simulation compared to standard modeling techniques.

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**CP36**

**Laser Spectral Waves: from Pattern Formation to Spatiotemporal Chaos**

Longitudinal modes of an inhomogeneously broadened laser can behave as a chain of locally coupled oscillators, which displays instabilities that are rarely observed in other media. The negative-slope dispersion relation governing wave propagation inside the spectrum induces cascades of parametric instabilities. Furthermore, the natural nonuniformities of the medium (the lasing line shape) lead to recurrent phase-slips (ramp-induced Eckhaus instabilities). We observe each of these mechanisms and their related spatiotemporal chaos in a fiber laser experiment.

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**CP36**

**Weak Synchronization of Chaotic Coupled Map**

**Lattices**

Phase synchronized states can emerge in the collective behavior of an ensemble of chaotic coupled map lattices, due to a mean field interaction. This kind of interaction is responsible for synchronized chaotic global activities of the lattices, while the local activity of each map remains unsynchronized. The resulting collective dynamics is called "weak synchronization". The transition to such a state is characterized in an ensemble of one-dimensional lattices of logistic maps, in terms of the distance in phase among the different lattices. Its robustness against a small difference in the map parameters is proved. This phenomenon can be associated with pattern formation.

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**CP36****Synchronized Finger Tapping and  $1/f^\alpha$  Type Long Memory Processes**

Imagine tapping your finger on a computer keyboard in synchrony with a periodic sequence of auditory beeps. The variability of your behavior is quantified by the small error you make on each tap. In particular, using an array of analytical techniques including the rescaled range analysis and the spectral maximum likelihood estimator, we establish that the synchronization error time series exhibits  $1/f^\alpha$  type of long memory where  $\alpha$  is about 0.5. We discuss the possible origin and functions of this process and point out future research directions

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**CP36****Understanding Phase Synchronization in Terms of Periodic Orbits**

Phase synchronization of chaotic oscillators can occur through phase-locking properties of the unstable periodic orbits embedded in a chaotic attractor. For each such orbit the phase-locked region can be constructed; we observe full phase synchronization when these regions overlap. The transition to this state arises via attractor-repeller collision.

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**CP36****Destruction of Resonances in Two-Mode Quasilinear Dynamical Systems**

Destruction of quasiperiodic oscillations through the interaction of two resonantly coupled modes is studied. The cases with  $m < 5$ , where  $m$  is the mode eigenfrequencies ratio, undergo detailed investigation. Equilibrium points properties are analyzed, conditions of the saddle-type points are found, the separatrix loop solutions are obtained analytically. Conditions of the invariant manifolds intersection under external periodic perturbation are found using Melnikov's technique.

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**CP37****Spinodal Decomposition for the Cahn-Hilliard-Cook Equation - Linear Theory**

The talk addresses the spinodal decomposition for the linearized stochastic Cahn-Hilliard-Cook equation  $u_t = -\epsilon^2 \Delta^2 u - \Delta u + \xi$  in  $\Omega$  with Neumann and no flux boundary conditions.  $\Omega$  is a domain with sufficiently smooth boundary and  $\xi$  a stochastic white noise. Based on the work of Maier-Paape and Wanner for the Cahn-Hilliard equation, it is shown, that with high probability a solution starting at  $u = 0$  leaves a neighborhood of 0 along a strongly unstable manifold, provided  $\epsilon$  small enough, which gives solutions with a characteristic wavelength.

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**CP37****Pattern Evolution in the Discrete Cahn-Hilliard Equation**

Lattice differential equations of Cahn-Hilliard type have solutions that exhibit similar behavior to that of the solutions of the analogous partial differential equation (such as spinodal decomposition followed by slow coarsening), in addition to lattice-induced effects not present in the spatially-continuous model. We will discuss the evolution of solutions on finite lattices, with emphasis on those phenomena unique to lattices and on the way that the grain pattern of the solution evolves.

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**CP37****Existence of Connecting Orbits in Cahn-Hilliard**

Using techniques based on Conley's connection matrix we will discuss the existence and structure of connecting orbits in Cahn-Hilliard.

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**CP37****Allen-Cahn/Cahn-Hilliard Systems with Degenerate Mobility**

Allen-Cahn/Cahn-Hilliard systems arise naturally in the context of modelling phase transitions exhibiting simultaneous order-disorder and phase separation. The degeneracy of the mobility reflects a possible vanishing of the mobility in the "pure" phases. Such systems can contribute to the understanding of wetting, prewetting, and interfacial adsorption phenomena. Existence results are presented for the degenerate system.

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**CP37****Spinodal Decomposition for the Cahn-Hilliard Equation**

If a homogeneous high-temperature mixture of metallic components is rapidly quenched to a certain lower temperature, then a sudden phase separation sets in. The mixture quickly becomes inhomogeneous and forms a fine-grained structure. This effect is called spinodal decomposition. My talk will describe numerical and theoretical results, explaining the mechanism for spinodal decomposition for binary and ternary alloys.

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**CP37****Pattern Formation and Spatial Entropy in Spatially Discrete Cahn-Hilliard Equations**

We consider arrays of scalar differential equations organized on a spatial lattice in a form analogous to the Cahn-Hilliard partial differential equation. With the so-called double obstacle nonlinearity we consider the existence and stability of a class of equilibrium solutions called mosaic solutions that take only the values +1, -1, and 0. We provide criteria for weak Lyapunov and weak asymptotic stability. Rigorous results are then obtained for the spatial entropy of these stable mosaic solutions.

Erik S. Van Vleck

**CP38****Fronts and Pulses in Reaction-Diffusion Equations and Their Stability**

We reduce certain reaction-diffusion equations with two time scales by a traveling wave Ansatz to obtain a system of singularly perturbed ODEs. Homoclinic or heteroclinic solutions of the ODE system represent traveling front or pulse solutions of the original equations. By geometrical methods we find homo- and heteroclinic orbits with multiple loops, corresponding to solutions with multiple fronts or pulses. In the original reaction diffusion equations we study stability of these patterns.

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**CP38****The Coupled, Weakly-Nonlinear Evolution of Two Counter-Rotating Waves and The Associated Streaming Flow in Finite Geometries**

A novel set of coupled amplitude-streaming flow (CASF) equations will be presented, that includes the coupled evolution of two counter-rotating waves and the associated streaming flow, in finite geometries (such as the capillary bridge geometry), under nonaxisymmetric forcing. The CASF equations will be discussed, and several numerically obtained results will be presented and explained on the light of linear stability properties of the simplest standing wave solutions.

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**CP38****Linear Conversion of Parallel Waves**

Consider two waves propagating in one direction and separately trapped in another direction, with small overlap of the two wave-fields. The energy of one wave is gradually transferred to the other, if they are locally resonant; i.e., they have (locally) equal frequency and wave-number. As an application of our general theory, we consider tropical-Atlantic low-frequency (period  $\sim 3$  weeks), long-wave (wave-length  $\sim 1000$  km) internal waves involving vertical displacement of the thermocline.

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**CP38****Dynamics of Counterpropagating Waves in Parametrically Forced Systems**

Parametrically forced counterpropagating waves in weakly dissipative fluid systems of moderately large aspect ratio are described by a pair of nonlocal equations for the (complex) amplitudes of the waves. These equations are solved in both annular and bounded geometries with sidewalls. Aside from spatially uniform standing waves these equations also describe spatially nonuniform states with simple and complex time-dependence. The nature of these states and transitions among them are investigated as a function of the forcing.

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**CP38****Dynamics of Solitary Pulses in Isotropic and Anisotropic Reaction Diffusion Systems**

Concentration pulses in a model of CO oxidation on Pt(110) undergo different types of instabilities (from modulated travelling waves, to "backfiring" and spatiotemporal chaos) as problem parameters vary. These instabilities are studied in parallel in the PDE and through the travelling waves ODEs. Pulse dynamics in thin annular anisotropic domains are reduced to that in 1-D media with position dependent properties. The effects of anisotropy are probed using simulation and numerical bifurcation analysis.

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**CP38****Dynamics, Bifurcations, and Stability of Fronts in the Optical Parametric Oscillator**

We consider the dynamics, stability and bifurcation of front structures of the optical parametric oscillator. Front solutions bifurcate super-critically from the trivial solution to a neutrally stable, translationally invariant front. Perturbations such as white-noise, group-velocity walk-off, or non-uniform pumping simply shift the center position of the front solution. For 2D fronts, the front curvature is governed by the heat equation so that only stripes are supported for long times.

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**CP39****Non-Local Reaction-Diffusion Equations for Microwave Heating Applications**

Motivated by recent microwave heating experiments on ceramic fibers in single-mode cavities, we present a new geometric approach to establishing the existence and stability of  $n$ -pulse solutions of a non-local reaction diffusion equation. Existence of solutions is determined by showing that the pulses lie in the transverse intersection of relevant invariant manifolds. The transverse intersection encodes a consistency condition that all non-local equations must satisfy. Stability is determined by locating the spectrum of a non-local Sturm-Liouville operator. We show that the  $n$ -pulse is metastable if  $n = 1$  and unstable otherwise.

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**CP39****Nonlinear Physical Forcing of Biological Populations**

The relative contributions of physical and biological processes in forcing natural populations remains a central issue in population dynamics. Here, I demonstrate that the episodic nature of the re-supply of certain open marine populations can arise through nonlinear biological responses to random physical forcing. This suggests that biological processes can act as a non-linear amplifier of environmental fluctuations. Nonlinear techniques may therefore succeed where linear methods have failed in detecting physical forcing in natural systems.

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**CP39****Spatially Complex Localisation in Twisted Constrained Elastic Rods**

We study localized deformations of twisted rods constrained to either a planar or cylindrical surface. Such rods have applications in, e.g., drill strings and pipelines. Localised solutions are described by homoclinic orbits to a periodic solution representing a spatially-homogeneous rod. For isotropic rods we recover results for the elastica and the helix, with twist simply being superimposed. For anisotropic rods we find spatial chaos with an infinity of localised solutions, a sample of which are computed using a shooting method. In the cylindrical case a central role is played by a heteroclinic tangency.

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**CP39****Weather Prediction and Residual Delay Maps: Isolating Regions of Atmospheric Nonlinearity to Compare Different Atmospheric Models**

Residual Delay Maps have been used in the past to show how to extract additional dynamical information from univariate, noisy time series. One application has been to improve local weather prediction. We extend these results to identify regions of the atmosphere where nonlinearity is an essential component of the natural dynamics. With these results, we provide a qualitative test for comparing different atmospheric models and in the process of doing so we uncover some striking new observations about the global atmospheric system.

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**CP39****Detecting Invariant Manifolds in Time Series: Biological Data**

Special dynamical behaviors like synchronization, collective behavior, and pattern formation are often the result of a system evolving on an invariant, lower-dimensional mani-

fold in its state space. Approaches for searching for dynamical manifolds using experimental time series are presented. In particular, one derived from a statistic for continuity shows evidence for an invariant manifold in coupled lobster neurons despite the lack of simple synchronization or any cross correlation between the neurons.

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**CP40****Dynamics of a Chaotic Magnetic Limiter in Tokamaks**

A symplectic mapping of magnetic field lines in a Tokamak perturbed by a chaotic limiter is presented. Bifurcation sequences are controlled by the resonant perturbations, which create structures on the parameter plane interpreted as a process of growing and destruction of secondary islands.

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**CP40****Power Limited Optimal Rendezvous Between Spacecraft**

The minimum-fuel rendezvous problem between several power-limited low-thrust spacecraft in the neighborhood of circular or elliptic orbits is investigated. Cooperative maneuvers are simulated using the maximum principle of Pontryagin. Planar motions in the Clohessy-Wiltshire and the inverse square law gravitational fields are treated. Numerical solutions using shooting methods as well as finite-difference methods were used to solve the resulting two-point boundary value problems.

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**CP40****Evolving Perturbed Hamiltonian Systems with Lie Transformations**

Time evolution of a Hamiltonian system can be considered a canonical transformation and thus represented by Lie transformations. Methods for perturbations included in the phase space were developed by Dragt and coworkers; here I generalize to all perturbed Hamiltonian systems. Perturbation parameters need not be associated with the phase space variables: both "internal" and "external" perturbations are treated equivalently. Applications to areas as diverse as celestial mechanics, accelerator physics and light optics are possible.

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#### CP40

##### **Experimental Observation of Chaos in a Plasma Discharge Tube**

Contemporary Geissler tube configuration and drive circuits will be introduced. Experimental configurations for observing light intensity as a function of time at multiple configurations, hybrid imaging, and digital high-speed video techniques will be presented. Data-visualization techniques provide a powerful mechanism for combining the acquired data and imagery to build a coherent understanding of the system's behavior.

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#### CP40

##### **Solutions of the Vlasov-Fokker-Planck Equation for Electrons in a Storage Ring**

The V-F-P equation describes harmonic synchrotron oscillations perturbed by the self-field of the charge distribution and noisy synchrotron radiation. It is a nonlinear functional-differential equation for the distribution function  $\psi(q, p, t) : \mathbf{R}^2 \times \mathbf{R} \rightarrow \mathbf{R}^+$ . The equilibrium solution is given by a nonlinear integral equation that is analyzed by a fixed-point method and solved numerically. The time-dependent problem is treated as a system of ODE's, after discretization in  $(q, p)$ .

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#### CP40

##### **An Optimal Control Problem for Satellite Dynamics via Wavelets**

We consider applications of methods from wavelet analysis to optimal control problem for spacecraft dynamics. We present constructions which give explicit in time representations for the controlling and controllable variables in different types of well localized bases for the general classes of functional spaces with sparse representation for the corresponding operators. We also consider the problem of practical realization of the computed solutions and applications to problems of chaotic dynamics.

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#### CP41

##### **Modelling Edge Detection Using A Network Of Pulse-Coupled Neurons**

A simulation of an edge detector using a biologically realistic pulse-coupled neural network is presented. A static 2D image is mapped onto a grid of units, which oscillate in synchrony in the absence of image stimulus. Edges are phase-coded and detected as units that are out of phase with their neighbours. The problem is formulated and analysed from a dynamical systems perspective.

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#### CP41

##### **Complex Behavior in Quasiperiodically Forced Biological Oscillators**

We study biological oscillators subject to the influence of two external periodic signals with incommensurate frequencies. These oscillators can exhibit a complex behavior without being chaotic. The corresponding attractors can be characterized as structures in-between regularity and chaos. They are nonchaotic in the dynamical sense but they have a strange geometrical structure. We discuss their appearance due to collision bifurcations between stable and unstable invariant sets as well as the consequences of their existence for phase-lockings.

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#### CP41

##### **Synchronization of Noisy Systems by Stochastic Signals**

The nonlinear response of noisy bistable and neuron systems to stochastic external signal, represented by Markovian dichotomic noise, is studied in terms of synchronization. We propose a general kinetic model, which allowed us to conduct a full analytical study of nonlinear response, including calculation of cross-correlation measures, the mean switching frequency and synchronization regions. We have shown, that dichotomic noise can synchronize instantaneously the switching process of the system.

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**CP41****Detecting Weak Interaction from Bivariate Data**

Weak forcing of a noisy chaotic oscillator by another one, or interaction of such oscillators, may result in their phase synchronization. Here we use this idea to approach the inverse problem: to reveal a weak interaction from bivariate time series. As examples we study interrelation between human cardiovascular and respiratory systems and between brain areas involved in generation of pathological movements (Parkinsonian tremor). The information we extract cannot be obtained by traditional linear techniques.

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**CP41****Embedding and Reconstruction of Forced systems**

The analysis and interpretation of time series obtained from dynamical systems is usually based on delay reconstruction methods. These rely on Takens Embedding Theorem for their justification. When systems are forced, whether deterministically or stochastically, this theorem is not applicable. We describe how to extend it to forced systems and discuss the implications for the structure of the resulting time series. Finally, we speculate on the generalization of these ideas to spatio-temporal systems.

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**CP42****Instabilities of Hexagonal Pattern in the Presence of Rotation**

Stimulated by the complex dynamics of rolls in rotating convection we study the stability of hexagonal patterns with broken chiral symmetry. Within a model of three coupled Ginzburg-Landau equations we consider the stability of both stationary and oscillating hexagons. In the latter case we derive the equation for the amplitude of the oscillation, coupled to the two translation modes of the underlying hexagonal pattern. The stability results are compared with numerical simulations.

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**CP42****An Analysis of Cellular Flame Patterns**

A method to analyze cellular flame patterns on a circular domain is presented. The first step is a modal decomposition through Karhunen-Loëve (KL) decomposition. Pairs of KL-modes are then combined to form effective Fourier-Bessel modes, which allow the deduction of complex time-dependent amplitudes from experimental states. Their symmetries are used to deduce the normal form equations. Applications to the analysis to rotating rings of cells and "hopping" states will be presented.

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**CP42****Cross-Newell Equations for Triangles and Hexagons**

This paper derives the Cross-Newell equations for triangular and hexagonal patterns in a large aspect ratio system. In general the resulting phase equations cannot be written in flux-divergence form, in contrast to the case of roll patterns. The consequences for defect formation in extended hexagonal patterns are explored. The phase stability boundaries for hexagons are also recovered from the phase equations in this new formalism.

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**CP42****Super-Patterns and Parameter Collapse in Reaction-Diffusion Systems**

A bifurcation analysis near a Turing instability determines the relative stability of simple patterns (stripes, hexagons) and more exotic, spatially periodic "super" patterns in reaction-diffusion systems. Explicit calculation shows that all system parameters collapse into relatively few effective parameters within the bifurcation equation coefficients. Moreover, in two-component systems several effective parameters disappear completely from the standard degenerate hexagonal lattice bifurcation problem. Nevertheless, even with these restrictions super-patterns may indeed form stably.

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#### **CP42**

#### **Modal Decomposition of Hopping States in Cellular Flames**

We use Karhunen-Loëve (KL) decomposition of video images from an experiment to analyze a spatio-temporal dynamic state, unique to cellular flames, referred to as "hopping states". KL decomposition separates the spatial and temporal characteristics of the hopping motion. The underlying symmetries of the experiment allow us to deduce a set of normal form equations to describe the bifurcation and evolution of these states.

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#### **CP42**

#### **Multibump Patterns Near a Co-Dimension 2 Point**

The behaviour of marginally unstable small solutions in a reaction-diffusion model problem is studied near a co-dimension 2 point. At this co-dimension 2 point the 'classical' Ginzburg-Landau (GL) equation approximation breaks down. It is shown that the evolution of small solutions is described by different types of extended Fisher-Kolmogorov equations. The asymptotic analysis is compared to numerical simulations: asymptotically stable multibump patterns are observed. These multibump patterns are found theoretically by applying normal form theory.

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#### **CP43**

#### **Topological Bifurcations in the Vortex Breakdown**

A vortex breakdown is the creation of secondary flow structures in rotating flows. We develop a normal form for streamline patterns from which bifurcations up to co-dimension 3 are easily constructed. The bifurcation diagrams are used in conjunction with numerical simulations to systematically determine the bifurcation diagram for the much studied flow in a closed container with rotating end-covers. Good agreement with experimental results is obtained, and some hitherto unresolved details are de-

termined.

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#### **CP43**

#### **Tracer Dynamics in a Flow of Driven Vortices**

We report on the Lagrangian dynamics of an array of driven vortices for which a low-dimensional streamfunction model was derived from numerical computations of the two-dimensional Navier-Stokes equations. We give evidence that the dynamics of passive tracers is essentially controlled by the existence of a chaotic saddle for which its stable and unstable manifolds are approximated. By introducing symbolic dynamics, we characterize the spatiotemporal properties of the tracers by the Shannon entropy.

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#### **CP43**

#### **Five Point Vortices which Exhibit Relaxation Oscillation**

The motion of assembly of point vortices in the two-dimensional Euler flow is a classical problem, which is described by a ordinary differential equation. For some five point vortices problem, a corotating motion with relaxation oscillation occurs for some vortex strengths. The purpose of this talk is to analyze such a motion. To this end we prove the existence of heteroclinic orbits. It is also shown periodic and chaotic motions of the vortices.

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#### **CP43**

#### **Chaotic Dynamics in Vortex Cores**

Vortex-blob computations were performed for the roll-up of a planar and an axisymmetric vortex sheet into a vortex pair and a vortex ring, respectively. The computations reveal the onset of chaotic dynamics due to resonance phenomena in the vortex core and a heteroclinic tangle at the rear of the vortex ring. The chaos arises from self-sustained

oscillations in the core vorticity. We investigate the extent to which the observed dynamics are present in real (viscous) flows.

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#### **CP43**

#### **Instabilities of Vortex Filaments in Oscillatory Media**

We study vortex filaments subjected to a uniform density of phase twist in three-dimensional oscillatory media. We show that, in a large region of parameter space, the first instability is a supercritical Hopf bifurcation to stable propagating helical vortices and that the secondary instability, leads to quasiperiodic supercoiled filaments. Further regimes are also discussed. We comment on the similarity between the changes undergone by these dynamical objects and those of twisted elastic rods.

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#### **CP44**

#### **Numerical Simulations of Complex Flows of LCPs Based on the Doi Theory**

In this talk, we present numerical simulations of inhomogeneous flows of liquid-crystalline polymers. The Doi theory, with a closure approximation, is used for the calculations. Based on the results, we explore the mechanisms for the generation of disclinations and the effects of the coupling between flow and the polymer configuration. Channel flows with expansions experience a peculiar instability which bears remarkable resemblance to patterns observed in experiments.

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#### **CP44**

#### **A Continuum-Mechanical Theory for Nematic Elastomers**

We develop a continuum theory for the mechanical behavior of rubber-like solids that have been formed by the cross-

linking of polymeric fluids which include nematic molecules as elements of their main-chains and/or as pendant side-groups.

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#### **CP44**

#### **Stress Selection and Phase Separation in the Doi Model for Solutions of Liquid Crystalline Polymers**

Many complex fluids exhibit "phase transitions" in shear flow. I will discuss a modified version of the Doi model for rigid-rod suspensions. By incorporating spatial gradients we can unambiguously calculate the "phase boundaries" in shear flow, for which coexistence corresponds to a heteroclinic orbit in an equivalent dynamical system. I will explore some qualitative aspects of phase separation in shear flow, and discuss simpler model calculations which investigate the effects of curved boundary conditions.

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#### **CP44**

#### **Capillary Instability in Free Surface Jets of Liquid Crystal Polymers**

We investigate the capillary instability for free surface jet flows of liquid crystal polymers using a Doi type theory for homogeneous liquid crystals. We also consider the influence of surface elastic effects arising from the possible deviation between the orientation in the bulk and the preferred surface orientation. Restricting to slender jets, we address the issue of transient stability for two special jets under the influence of gravity, in which the orientation induced axial stress plays the dominant role in determining stability.

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#### **CP44**

#### **Nonisothermal Spinning of Lyotropic and Thermotropic Liquid Crystalline Polymers**

Previous slender one-dimensional models for axisymmetric filaments of liquid crystalline polymers (LCPs) are extended to include temperature-dependent material behavior and an energy equation. We present families of numerical steady boundary-value solutions for thermal spinning flows; effects such as temperature-dependent viscosity and LCP relaxation are modeled and exhibited. The predictions focus on thermal influence on spun fiber performance properties and process stability. This is joint work with M.G. Forest and Q. Wang.

#### Hong Zhou

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**MS01****Regenerative Effect and Chatter: An Analytical Study**

A phenomenon commonly encountered during machining operations is chatter. It manifests itself as a vibration between workpiece and cutting tool, leading to poor surface finish and dimensional accuracy of the workpiece and reducing the useful life of the cutter. The onset of chatter acts as an upper bound on the cutting speed, limiting material removal rates and productivity. The mathematical models representing chatter dynamics have been cast as differential equations with delay, admitting periodic, quasi-periodic and aperiodic tool vibrations. By adapting existing mathematical techniques, we shall obtain finite-dimensional equations in order to systematically study the nonlinear behavior of machine tool chatter.

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**MS01****Nonexpansive Periodic Operators in  $\ell_1(\mathbb{Z})$  and Super-high-frequency Solutions of a Discontinuous Differential-Delay Equation**

We study the discontinuous differential delay equation

$$x'(t) = -\operatorname{sgn}(x(t-1)) + f(x(t)) \quad (0.2)$$

where

$$\begin{aligned} \operatorname{sgn}(x) &= 1 \quad \text{for } x < 0, \\ \operatorname{sgn}(0) &= 0, \end{aligned}$$

and

$$\operatorname{sgn}(x) = -1 \quad \text{for } x > 0.$$

We assume that  $f$  is locally Lipschitzian and that  $|f(x)| < 1$  for all  $x$ . Suppose that  $x|[-1, 0] = \varphi$  and  $x(t)$  satisfies (0.1) for  $t \geq 0$ . If  $\varphi$  is not identically zero or if  $f(0) \neq 0$ , we prove that there exist  $t_\varphi \geq 0$  and an integer  $n_\varphi$  such that  $x$  has at most  $n_\varphi$  zeros on any interval  $(t-1, t)$  for  $t \geq t_\varphi$ . A key role is played by the study of certain "periodic" nonlinear operators  $\Phi : \ell_1(\mathbb{Z}) \rightarrow \ell_1(\mathbb{Z})$  which do not increase distance. The operators  $\Phi$  have independent interest.

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**MS01****Dynamics of Time-Delayed Ring Laser Systems**

The light produced by erbium doped fiber ring lasers, of direct relevance to optical communications, is often chaotic in its dynamics. A rich variety of temporal patterns of the light intensity and very interesting fluctuations of the light polarization are observed. These very long cavity fiber lasers may be described by delay equations for the electric field and a coupled differential equation for the population inversion, based on the Ikeda model. We will compare experimental observations to predictions from the model and examine the influence of noise sources on the dynamics.

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**MS01****Delay and Traveling Waves in Reaction-Diffusion Equations**

We consider traveling wave solutions in delayed reaction diffusion equations. By using monotone dynamical systems approach, we establish some existence results. We then apply these results to some particular equations to obtain delay-induced traveling waves.

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**MS02****Experimental Evaluation of Several Proposed Criteria for Synchronization**

We couple two electronic oscillators to evaluate several recently proposed criteria for synchronization. The oscillators reside on a stable periodic orbit but small perturbations due to noise can give rise to large transient excursions from the orbit. We compare the range of coupling strengths over which a high degree of synchronization is observed with the theoretical predictions. We find that most of the criteria fail because they are not sensitive to transient growth of perturbations.

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**MS02****Using Two-Attractor Chaotic Systems for Communication**

Self-synchronizing chaotic systems, used for communications, are very sensitive to noise. We show a technique for communicating using a chaotic system with two attractors, with the attractors as communications symbols. We are able to improve the noise robustness of chaotic communication compared to parameter modulation. Our chaotic receiver displays some interesting physics- it recognizes which attractor the transmitter is in, but does not actually syn-

chronize to the transmitter, not even in the general sense.

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### MS02

#### Invariant Manifolds and Chaotic Synchronization

The theory of k-hyperbolic invariant manifolds offers a natural framework for the study of chaotic synchronization. Many of the different types of synchronization that have been studied can be readily described in this framework. Furthermore this view provides both natural conditions for the persistence of smooth synchronization and a new set of Lyapunov type numbers to determine the onset of synchronization and leads to a duality between unidirectional and bidirectional synchronized systems.

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### MS02

#### Unstable Dimension Variability and Modeling of Coupled Chaotic Oscillators

Systems of coupled chaotic oscillators arise in many situations of physical and biological interest. We present an analysis and numerical evidence for a particular type of nonhyperbolic behavior in these systems: *unstable dimension variability*. We show that unstable periodic orbits embedded in the chaotic attractor in the synchronization manifold of the system typically have distinct numbers of unstable directions. The consequence of this type of nonhyperbolicity is severe: the system cannot be modeled deterministically in the sense that no model trajectory can be realized by the natural system that the model is supposed to describe. We argue that unstable dimension variability arises for arbitrarily small values of the coupling constant.

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### MS03

#### Recurrence Plots Revisited

We show that recurrence plots give detailed characterizations of non-stationary time series generated by dynamical systems driven by slowly varying external forces. For deterministic systems we can infer information about the driving force from the recurrence plot of the time series. Similar results hold for stochastic systems, when the recurrence plot is suitably averaged and transformed. These results are used for time series prediction and for detection

of small changes in the driving forces.

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### MS03

#### Coping With Non-Stationarity By Over-Embedding

Drifting parameters as the source of non-stationarity of otherwise almost deterministic systems can be identified by a reconstruction of an extended phase space by the method of delays. We discuss under which conditions the deterministic dynamics and the non-observed drifting parameters can be reconstructed implicitly. This concept is applied to numerically generated data and to human speech.

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Thomas Schreiber  
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### MS03

#### Clusters As Basis for Study of Nonstationary Time Series

Many nonstationary signals may be viewed as the output of a dynamical system that moves around in parameter space in the course of the measurement period. We propose to use clusters of episodes with similar dynamics as an empirical basis in parameter space. We discuss measures of dynamical similarity and show some simple applications.

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### MS03

#### Testing Stationarity in Time Series

We propose a procedure for testing stationarity of time series by combining a test for time independence of the 1D probability density with one of the spectral density. The potentials and limits of this test procedure are established by its application to different types of numerically generated time series ranging from simple linear stochastic processes to high-dimensional transient chaos as well as to observational data from geophysics and physiology.

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### MS04

#### Equilibrium Statistics and Dynamics of Point Vor-

### **tices on a Rotating Sphere**

Large scale coherent structures of barotropic flows on a sphere are characterized in terms of the most probable states of a statistical mean field theory (MFT). This MFT is obtained by formulating the Onsager-Joyce-Montgomery (OJM) theory in spherical geometry, starting from the spherical point vortex model (SPVM). The hamiltonian structure and symmetries give rise to the constraints in a maximum entropy derivation of the mean field equations. A second derivation uses the Bogoliubov-Feynman inequality for the free energy.

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### **MS04**

#### **Discrete Euler-Poincaré and Lie-Poisson Equations**

Discrete analogues of Euler-Poincaré and Lie-Poisson reduction theory are developed for systems on finite dimensional Lie groups  $G$  with Lagrangians  $\mathcal{L} : TG \rightarrow \mathbb{R}$  that are  $G$ -invariant. These discrete equations provide "reduced" numerical algorithms - discrete Euler-Poincaré (DEP) equations - which preserve the symplectic structure. Reconstruction recovers the discrete Euler-Lagrange equations which are symplectic-momentum algorithms. The solution of the DEP algorithm leads to a discrete Lie-Poisson algorithm. As an application, a reduced symplectic integrator for two dimensional hydrodynamics is constructed.

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### **MS04**

#### **Finite Symmetry Methods for $N$ Identical Vortices on the Sphere**

I will describe joint work with Mark Roberts and Chjan Lim, in which we use the actions of both the rotation group and the permutation group to prove the existence of many relative equilibria for systems of identical point vortices on the sphere. The symmetry types of the relative equilibria can be used to block-diagonalize the hessian of the augmented Hamiltonian so simplifying the stability calculations. Both 'direct' and time-reversing symmetries are used.

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### **MS04**

#### **Integrable Vortex Dynamics On A Sphere**

We will describe the integrable structure of point vortices of arbitrary strength moving on the surface of a sphere. First, we will introduce the basic Hamiltonian structure, along with conserved quantities and an overview of the integrable three vortex problem. Then, we will focus on the geometry of three vortex collisions. Finally, we will describe the topology of streamline patterns on the sphere and the corresponding stereographic plane, whose Hamil-

tonian structure will be shown.

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### **MS05**

#### **Cargo Transfer with Shipboard Cranes: Control, Prediction, and Simulation**

Ships with onboard cranes are used by the U.S. Navy and others to transfer cargo from larger ships to smaller ships for transport to shore. Rough seas can induce cargo pendulation and oscillation of the landing platform, making operations using existing control mechanisms infeasible. I will give an overview of work by the Maryland Chaos Group on simulation of the dynamics, design modifications, and procedures for safe transfer and landing of cargo in moderately rough seas.

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### **MS05**

#### **Generating Random Numbers Via Deterministic Chaos**

A random number generator (RNG) based on a 2-regions 1D chaotic map is analysed, which overcomes the drawbacks of classical RNGs: inability to analyse and optimise the RNG, inability to compute probabilities and entropy of the RNG, and inconclusiveness of statistical tests. We exploit the deterministic part of the nature of chaos and the simplicity of the 1D map to extend existing works on chaos-based RNGs, and to give mathematical analysis of the information generation mechanism.

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### **MS05**

#### **Chaotic Dynamics and Modeling of Power System Loads**

Electric arc furnaces are used in smelting and steel production. They also can cause significant degradations of electric power quality. This talk discusses the results of an interdisciplinary collaboration wherein ideas of nonlinear dynamics have been applied to model the operation of highly varying loads, such as electric arc furnaces, on power distribution networks. The analysis of associated time series is also discussed.

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**MS05****Constructing Transportable Behavioural Models of Nonlinear Electronic Devices**

We describe a new technique for producing transportable behavioural models of nonlinear electronic devices. The behavioural models are reconstructed using time domain input-output data. The models have the ability to accurately predict the response of an electronic device over a wide range of operating points. We demonstrate our methods using simulated data from an Ebers-Moll transistor acting as a simple amplifier.

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**MS06****Ergodic Theory of Equivariant Diffeomorphisms**

We describe recent work, some joint with Matthew Nicol (UMIST) on the stability of ergodicity and mixing for diffeomorphisms equivariant by a compact Lie group. This work extends earlier work of Field, Parry and Pollicott on stability of ergodicity for skew extensions and involves a natural extension of the concept of Markov partition.

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**MS06****Ergodic Properties of a Class of Skew Products**

Let  $M$  be a compact manifold on which a connected Lie group  $G$  acts. Suppose  $\phi$  is a diffeomorphism of  $M$  which commutes with the  $G$ -action, such that the quotient diffeomorphism  $\phi/G$  on  $M/G$  is sufficiently hyperbolic (Anosov, say). Consider perturbations  $\tilde{\phi}$  of  $\phi$  such that  $\tilde{\phi}/G = \phi/G$ . When  $G$  is compact, such perturbations are known to be 'stably ergodic' (Field-Parry, Burns-Wilkinson). We discuss similar results when  $G$  is non-compact.

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**MS06****The Dynamics of a Class of Non-Uniformly Hyperbolic Attractor of Solenoid Type**

We study the dynamics of a new class of strongly dissipative non-uniformly hyperbolic attractors which can be regarded as a natural extension of the Axiom A solenoid. The set of critical points is constructed and its dynamics are fully understood. As the source of the non-hyperbolicity of the given system, the set of critical points plays the same role as that of critical points in one-dimensional maps.

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**MS06****Lyapunov Exponents and Partially Hyperbolic Systems**

We discuss numerical experiments and results that show that nonzero lyapunov exponents can be created from systems with zero exponents almost everywhere. (Joint work with Mike Shub, Chaiwah Wu)

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**MS07****Spatiotemporal Chaos in Electroconvection: An Application of Coupled CGL Equations**

Recently, a direct transition from a uniform state to a state that exhibited spatio-temporal chaos was observed in electroconvection of the nematic liquid crystal I52 (M. Dennin, et al., PRL (1996); Science (1996)). Also, a weakly nonlinear analysis of the fundamental equations of motion has provided the relevant coupled complex Ginzburg-Landau equations for this system (M. Treiber and L. Kramer, PRE (1998)). This combination presents a unique opportunity to make quantitative comparisons between theory and experiment that will significantly increase our understanding of spatial-temporal chaos.

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**MS07****The Complex Ginzburg Landau Equation: Connection to Physical Experiment**

The complex Ginzburg-Landau (CGL) equation is widely used as a generic model for nonlinear traveling wave pattern formation. Other than qualitative features, what can a CGL description say about the quantitative behavior of real physical systems? I will present experimental results for a traveling wave wall mode in rotating Rayleigh-Bénard convection which demonstrates the utility of the CGL equation

in accurately predicting experimental behavior.

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### MS07

#### Long Wavelength Behavior in the 1D Complex Ginzburg-Landau Equation

Previous work suggests replacing chaotic fluctuations with a noise term in long wavelength descriptions of spatiotemporal chaos. We demonstrate that the behavior of the chaotic 1D complex Ginzburg-Landau equation exhibits a crossover similar to that of the Kardar-Parisi-Zhang (KPZ) Langevin equation. Using large-scale computations we measure the KPZ coefficients as a function of system parameters and find that they agree well with our estimates based on simple scaling arguments.

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### MS07

#### Transition from Ordered to Disordered Defect Chaos

In numerical simulations of coupled complex Ginzburg-Landau equations describing parametrically excited waves we find a transition from a disordered to an *ordered* state of spatio-temporal chaos. While in the disordered chaotic state the defects in the wave pattern seem to perform a random walk, their dynamics are strongly correlated ('bound pairs') in the ordered chaotic state and the waves maintain an ordered stripe pattern. This is reflected in various spatio-temporal statistics of the defects.

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### MS08

#### Snaking Curves of Multibumps, Degenerate Hamiltonian Hopf Bifurcation and Cellular Buckling

Subcritical (nonintegrable) Hamiltonian-Hopf bifurcations are known to cause an infinity of multi-bump homoclinic orbits which have application in elastic buckling and to nonlinear waves. We consider a fourth-order Hamiltonian system with competing nonlinearities. Here the local bifurcation can become degenerate leading to a heteroclinic tangle. The ensuing snaking bifurcation curve may be used to describe the repeated localised buckling of a long struc-

ture cell by cell.

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### MS08

#### The Saddle-Focus Induced Homotopy Classes and Their Action Minimizing Orbits for Hamiltonian Systems With Two Degrees of Freedom

By the classical result of M. Morse, every homotopy class of curves on a closed surface of genus greater than one contains a length minimizing geodesics. We shall explain how this principle can be adapted to explore the action-minimizing solutions of (non-mechanical) Hamiltonian systems with two degrees of freedom that exhibit saddle-focus equilibria. Our primary example is the extended Fisher-Kolmogorov equation,  $u''' - \beta u'' + u(u^2 - 1) = 0$ , investigated in a joint research with W.D. Kalies, J.B. Vandenberg, and R.C.A.M. VanderVorst.

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### MS08

#### An Elliptic Equation with Spike Solutions Concentrating at Local Minima of the Laplacian

We examine a singularly perturbed equation that arises when one looks for standing wave solutions of the nonlinear Schrödinger equation. The equation contains a coefficient function. We find solutions that decay at infinity and concentrate near local minima of the function. Unlike in previous results, the minima may occur in unbounded components, and therefore are not "topologically stable" in the way that a strong local extremum or a saddle point is.

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### MS09

#### Bifurcations of Localized Structures in Lattice Systems

We demonstrate the scenario showing how the stable spatially localized solutions with nontrivial dynamics may appear in lattice dynamical systems. Bifurcations to such regimes occur when the strength of spatial interactions exceeds some threshold. Therefore these regimes were indeed created by spatial interactions rather than the ones existing as well in the lattices of noninteracting maps. Our approach can be applied to study bifurcations to nonstationary states with spatial structure of general type.

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### MS09

#### Collective Behavior of Lattices of Strongly-Coupled Chaotic Maps

Strongly-coupled chaotic map lattices exhibit non-trivial collective behavior. Their macroscopic dynamics becomes universal (similarly to single maps) in the continuous-space limit which arises from a renormalisation group approach. We briefly recall these facts before presenting a simple model, valid in all space dimensions, without any free parameter, which accounts well for the collective motion by reducing the dynamics of the system to a one-body distribution function coupled to a coherence length.

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### MS09

#### Symmetry and Control of Extended Dynamical Systems

The problem of controlling spatiotemporally chaotic dynamics of systems modeled by coupled map lattices is considered. Using linear stability analysis it can be shown that symmetry of the lattice plays a very important role in the problem and that the geometry of control is closely related to the geometry of the system itself. A scalable distributed control approach is introduced and the implications of theoretical results for actual experimental systems are discussed.

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### MS09

#### Existence, Uniqueness, and Smooth Dependence of Thermodynamic Limits of SRB-measures

We show that there exists a unique thermodynamic limit of SRB-measures over a weakly coupled hyperbolic map lattice. This limit has the usual properties of an SRB-measure. It can be represented as a Gibbs state of a higher dimensional lattice spin system of equilibrium statistical mechanics and it has a potential function with zero topological pressure. It depends smoothly on the coupled map lattice in suitable functional spaces.

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### MS10

#### Time-Stepping Algorithms with Controllable High-Frequency Dissipation for Nonlinear Dynamics

We introduce a new family of time-stepping algorithms for

nonlinear dynamics that exhibits a controllable numerical dissipation in the high-frequency. The main motivation behind these methods is the elimination of the error associated with the approximation of the high-frequency spectrum of continuous systems. A complete analysis of these methods will be presented, illustrating the treatment of other properties of the continuum problem (like conservation laws, associated momenta, etc). Representative numerical simulations in the context of the finite element method in elastodynamics will be also presented.

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### MS10

#### The Post-Processed Galerkin Method Applied to Nonlinear Shell Vibrations

We present the results of a computational study of the post-processed Galerkin method applied to the von Karman equations governing the motion of a thin cylindrical panel periodically forced by a transverse point load. We spatially discretize the shell using finite differences to produce a large system of ODEs and construct “flat Galerkin”, “nonlinear Galerkin” and “post-processed Galerkin” schemes for approximating the solution of the ODEs. We find the post-processed Galerkin scheme to be most efficient.

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### MS10

#### Geometric Exact Models, Energy-Momentum Methods, and Active Degrees of Freedom for the Dynamics of Shells and Rods

In various fields of applications, thin bodies are considered by means of one or two dimensional models, the so called rod or shell theories which are achieved as dimensionally reduced formulations of three-dimensional continua. The paper is concerned with: (1) The formulation of one-dimensional models of spatial rods as well as two-dimensional models of shells. (2) The finite element modelling of the nonlinear dynamics including finite deformations and chaotic motion. (3) The construction of stable energy-momentum integration schemes for long time simulations of such large systems. (4) Determining the active degrees of freedom of such models in order to apply the postprocessed Galerkin method to approximate inertial manifolds (in case they exist) for a possible dimension reduction of the dynamics of shells and rods using the finite

element method.

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**MS10**

**Nonlinear Oscillations of a Fluid Conveying Tube with an End Mass**

We investigate the three-dimensional dynamics of a fluid conveying tube with an end mass. In an experimental setup Moon and Copeland observed several oscillatory states, which differ from the pure plane and rotating waves predicted as primary solutions in rotatory symmetric systems. Using equivariant bifurcation theory and path following methods we relate some of these observed states to branches generated by higher order bifurcations.

**Alois Steindl, Hans Troger, and Bernhard Albrecht**

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**MS10**

**Postprocessing Galerkin Methods**

In this talk we will present a Postprocessing Procedure of the Galerkin method which involves the use of an approximate inertial manifold to model the high wavenumbers component of the solution in terms of the low wavenumbers. This postprocessed Galerkin method, which is much cheaper to implement computationally than the Nonlinear Galerkin (NLG) Method, possess the same rate of convergence (accuracy) as the simplest version of the NLG, which is more accurate than the standard Galerkin method. Our results valid in the context of spectral and finite element Galerkin methods and for many nonlinear parabolic equations including the Navier-Stokes equations. We will also present some computational study to support our analytical results.

**Edriss Titi**

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**MS11**

**Communicating with Chaos**

In this lecture, I will argue that we can utilize the close connection between the theory of chaotic systems and information theory to encode any desired message in an experimental chaotic signal and thereby use this signal as a communication source. I will show a movie in which this

experimental encoding is done in real time.

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**MS11**

**Communicating With Chaos Using Two-Dimensional Symbolic Dynamics**

Symbolic representations of controlled chaotic orbits can be used for communicating. We investigate communicating with chaos by using more realistic dynamical systems described by three-dimensional flows. It is difficult to specify a generating partition so that a good symbolic dynamics can be defined. A solution is proposed whereby hyperbolic chaotic saddles embedded in the attractor are exploited for digital encoding. Issues addressed include channel capacity and noise immunity when using these saddles for communication.

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**MS11**

**Redundant Chaotic Signals**

The intrinsic redundancy of controlled chaotic signals make them natural information carriers. A technique will be presented showing that this property can be used to reconstruct extensive amounts of missing parts to the chaotic signal. It also significantly improves the information capacity of the communication channel.

**Epaminondas Rosa, Jr.**

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**MS11**

**Communication with Chaotic Waveforms**

We review recent progress in the field of communication with chaotic optical systems and report the results of experiments with erbium doped ring lasers and optical fiber communication channels. The dynamics of these lasers are described by coupled delay-differential equations. The processes of message encoding and recovery with appropriately designed transmitters and receivers will be described.

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**MS12**

**The Topology of Explosions: Sudden Appearance of Recurrent Points**

A crisis is a sudden jump in the size of a chaotic attractor.

More generally, we call the discontinuous bifurcation of a component of the chain recurrent set, such as a chaotic saddle or attractor, an "explosion". We show that for a large class of planar maps, an explosion implies the existence of a homoclinic or heteroclinic tangency.

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#### **MS12**

##### **Topology of One-Dimensional Tilings**

Given a finite collection of one-dimensional "proto-tiles" (closed intervals), an inflation constant, and a substitution rule that expresses each inflated proto-tile as a union of proto-tiles laid end to end, there is an associated space of all permissible tilings of the real line with a natural topology. With mild assumptions on the nature of the substitution, we will show that if two such tiling spaces are homeomorphic then their associated substitution matrices are weakly equivalent.

#### Marcy Barge

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#### **MS12**

##### **Topological Horseshoes**

When does a map have chaotic dynamics in a closed set? More specifically, when does the map admit an invariant set in the closed such that the map restricted to that invariant set factors over the shift on m-symbols or a subshift of finite type? This work is an attempt to clarify some of the issues when no hyperbolicity is assumed. We then demonstrate some examples, including billiards, where our conclusions apply.

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#### **MS12**

##### **Topological Phenomena in the 3D Single Crystall Normal Metals**

The motion of quantum electrons along the Fermi Surfaces in the strong magnetic field leads to the nontrivial problems in the theory of Dynamical System and 3D Topology. Universal behavior of conductivity in the strong magnetic

field was found. The observable integer-valued Topological Quantities of the new type are predicted.

#### Serguei P. Novikov

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#### **MS13**

##### **Dynamic Control of Cardiac Alternans**

A dynamic control technique was used to suppress a cardiac arrhythmia called an alternans rhythm in a piece of dissected rabbit heart. Our control algorithm adapted to drifting system parameters, making it well-suited for the control of physiological rhythms. Control of cardiac alternans rhythms may have important clinical implications since they often precede serious cardiac arrhythmias and are a harbinger of sudden cardiac death.

#### Kevin Hall, Leon Glass

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#### Jacques Billette

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#### **MS13**

##### **Using Control Blindly to Find Unstable Periodic Orbits**

Biological experiments have employed Proportional Perturbation Feedback (PPF) control to stabilize periodic orbits. PPF control is based on the idea of placing the system's state on a stable manifold, but, I'll show, can be successful even without a stable manifold. In fact, PPF control can be used blindly, without knowing where there is a periodic orbit and may serve as a general experimental technique for studying excitable biological systems.

#### Daniel T. Kaplan

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#### **MS13**

##### **Shedding Light on Neuronal Dynamical "Dark Matter"**

Unstable periodic orbit (UPO) structure has been identified within neuronal systems. A striking feature of such UPO analysis has been the gaps of time within which no UPOs are resolvable - dynamical "dark matter". Since UPO extraction methods frequently assume that the underlying dynamics are differentiable, it is necessary that the functions be continuous. Periods of observed differentiability should be fully contained within periods of continuity.

We prove this is the case for a neuronal network.

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### MS13 Cross-Spectral Analysis of Tremor Time Series

We apply cross-spectral analysis to tremor time series and related signals. For the physiological tremor, analysis of the muscle activity and the tremor time series shows that this tremor is a resonance phenomenon and that the measured muscle activity represents a Newtonian force acting on the hand. For enhanced physiological tremor a statistical test for the contribution of reflexes is derived. An analysis including the EEG reveals the contribution of cortical activity to certain tremors.

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### MS14 Characterizations of Natural Patterns

Textured patterns are created via spontaneous symmetry breaking and exhibit "configuration independent" characteristics. A class of measures called the "disorder function",  $\bar{\delta}(\beta)$ , will be introduced to describe such features. Analysis of patterns shows that  $\bar{\delta}(\beta)$  is identical for multiple patterns generated under fixed external conditions. The relaxation of patterns from initially random states can be quantified using the time evolution of  $\bar{\delta}(\beta)$ . The creation of domains and their coarsening are shown to exhibit different characteristics.

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### MS14 Controling Turbulence by Global Feedbacks

Global delayed feedbacks are introduced into the complex Ginzburg-Landau equation. Their influence on diffusion-induced turbulence described by this equation is investigated by numerical simulations. We show that turbulence can always be suppressed by adjusting the feedback intensity and the delay time. In the presence of feedbacks, new types of spatiotemporal patterns are observed that include localized turbulent bubbles, phase strings and dynamical cellular structures

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### MS14 Characterisation and Control of Spatiotemporal Systems

We present here a method to characterize and control spatially extended nonlinear systems by an analysis of invariant measures, e.g. Lyapunov exponents, Lyapunov dimension, K-S entropy, in spatially localised regions. Variation of these invariant measures with increasing subsystem size shows interesting scaling relationship and reveals the existence of a critical subsystem size that may suffice in characterizing the full system dynamics. The method is quite general and works for both discrete and continuous dynamical systems.

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### MS14 A Wavelet-Based Investigation of A Spatiotemporally Chaotic System

We investigate the nature of spatiotemporal chaos in the Kuramoto-Sivashinsky partial differential equation, showing with the aid of a wavelet decomposition that the relevant dynamical interactions are localized in space and scale. Three characteristic regimes of the dynamics may be identified: large scales of slow Gaussian fluctuations, active scales containing interactions of coherent structures,

and small scales. Motivated by this characterization, we construct low-dimensional, spatially localized models for a minimal "chaotic box".

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#### Philip Holmes

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#### **MS14**

#### **Periodic Orbit Analysis of High Dimensional Spatiotemporal Chaos**

Motivated by low-dimensional periodic orbit theories, we compute hundreds of unstable periodic orbits (UPOs) and fixed points of the extensive chaotic Kuramoto-Sivashinsky (KS) equation. Using an escape-time weighting of UPOs, we are able to predict the long-time average spatial pattern of the KS equation, whereas trace formulas of UPOs are inapplicable. The error in the approximate average pattern scales as  $O(1/N)$ , where  $N$  is the number of computed UPOs and fixed points.

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#### **MS15**

#### **Soliton Perturbations and the Random Kepler Problem**

We consider a randomly perturbed Kepler problem. We reduce the problem, via an averaged Lagrangian approach, to a set of random ordinary differential equations. These are equivalent to a random Kepler problem. We calculate the Fokker-Planck equation governing the distribution of the soliton parameters. Using the action angle variables for the Kepler problem we are able to explicitly calculate the mean time to the destruction of the soliton in the weak noise limit.

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#### **MS15**

#### **Shilnikov Manifolds in Coupled Nonlinear Schrodinger Equations**

The forced-damped nonlinear Schrodinger equation (NLS) has been widely studied as a prototype of an infinite-dimensional near-integrable system that produces temporal chaos. In this talk we consider systems of coupled NLS equations and examine the origin of the spatio-temporal chaos observed numerically in such systems. We discuss single and multi-pulse homoclinic behavior and identify invariant manifolds resembling the shape of Shilnikov-type homoclinic orbits.

#### George Haller

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#### **MS15**

#### **Dynamics of Long Ring Lasers**

Spatio-temporal dynamics of a pumped ring-cavity laser are modeled by the Maxwell-Bloch partial differential equations with spatially periodic boundary conditions. Simulations show regular and irregular behavior depending on the cavity length, pumping strength, material relaxation rates, and cavity losses. Irregular dynamics are unidirectional waves whose speed and height vary in a seemingly random fashion, but whose other features, such as the number of "crests" per spatial period, remain approximately constant in time. Computed power spectra, attractor dimension, and two-point correlation functions indicate the low-dimensional nature of the solutions. The existence of spatially-dependent orbits homoclinic to an unstable saddle-focus will also be discussed.

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#### Ilya Timofeyev

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#### **MS15**

#### **Weak Turbulence with Applications to Semiconductor Lasers and Fiber Optics**

Based on a model Hamiltonian appropriate for the description of many-body fermionic systems such as semiconductor lasers, we describe a natural asymptotic closure of the BBGKY hierarchy by analogy with that derived for classical weak turbulence. We find a new class of solutions to the resulting quantum kinetic equation which are analogous to the Kolmogorov spectra of hydrodynamics and classical weak turbulence. These solutions involve finite fluxes of particles and energy in momentum space and are particularly relevant for describing the behavior of systems containing sources and sinks. We explore these solutions by using differential approximation to the kinetic equation. We show that when these solutions are excited in semiconductor laser, the laser has lower lasing threshold and is more efficient. I will also present how the developed formalism can be applied to the problems in fiber optics telecommunications.

#### Yuri Lvov

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**MS16****Numerical Analysis of Dynamic Contact/Impact in Elastic Multi-Body Systems**

We present new time-stepping algorithms for the integration of elastic multi-body dynamical systems that do not lead to an increase of the physical energy due to the contact interactions, thus leading to superior stability properties. In particular, the discrete frictional components preserve their physically dissipative character. We discuss the formulation and analysis of the newly proposed methods, as well as their numerical implementation in the context of the finite element method. Their performance is illustrated in representative numerical simulations.

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**MS16**  
**Variational Structure/Numerics of Contact Problems**

The purpose of this talk is to analyze a variational formulation of problems involving contact and friction. Some numerical examples are done using the Coulomb model of friction to illustrate the method.

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**MS16**  
**Symplectic-Energy-Momentum Integrators**

We shall discuss the theory and some simple examples of integrators for mechanical systems with symmetry that are symplectic (in a spacetime sense) as well as being momentum and energy preserving. The basic methodology is to use adaptive time steps together with discretizations of the variational principle. The relationship of this work with other work of the authors on contact problems will

also be discussed briefly.

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**MS17**  
**A Discrete Convolution Model for Phase Transitions**

We study an Ising-like model for phase transitions, incorporating long-range interactions. The dynamics of the state is according to an gradient flow for the Helmholtz free energy. We construct traveling and stationary waves and give criteria for propagation and pinning of a wave. Some results concerning uniqueness and stability of the wave are given.

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**MS17**  
**A Variant of Newton's Method for the Computation of Traveling Wave Solutions of Differential-Difference Equations**

We present a numerical method for finding traveling wave solutions to nonlinear bistable differential-difference equations using a standard BVP solver (*colmod*) through relaxation of the variational equation. Traveling wave solutions satisfy a two-point boundary value problem but standard BVP codes do not handle the discrete difference terms. Examples included demonstrate propagation failure, lattice anisotropy, bifurcation points in the wave speed and detuning parameter relation, and step-like solution profiles.

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**MS17****Mosaic Solutions and Entropy for Spatially Discrete Cahn-Hilliard Equations**

We consider a differential equation on a spatially discrete lattice which is analogous to the *Cahn-Hilliard* equation, but which need not be near a continuum limit. We prove existence of solutions for the *double obstacle* nonlinearity and consider the existence and weak-stability of *mosaic solutions*, which are equilibrium solutions which only take the values +1, -1 and 0 at each lattice point. Rigorous results are given for the spatial entropy of stable mosaic solutions.

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**MS17****Crystallographic Pinning: Direction Dependent Traveling Waves in Higher Dimensional Lattices**

We study traveling waves in networks of ODE's modelled on a high-dimensional lattice, and are interested in how wave speeds depend on the direction of motion. Crystallographic pinning occurs when a wave ceases moving in selected directions, and was examined in previous work with John Cahn and Erik Van Vleck for special systems. Here, we show how the phenomenon can be understood from general principles of dynamical systems.

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**MS18****Nonlinear Evolution and Chaos in the Kelvin-Helmholtz Instability of High Velocity Anisotropic Shear Layers**

The nonlinear instability of two layers of sheared compressible anisotropic plasma, which is important in astrophysics and geophysics, is studied under external driving. The solutions of the amplitude evolution equation derived for the marginally unstable regions using reductive perturbative methods are considered to obtain the parameter regimes where either a. the solutions evolve to final permanent wave patterns resembling empirically-observed vortex ensembles, or b. are disrupted by nonlinear modulational instability. A Melnikov function formulation for the problem is also developed, and reveals the existence of transverse homoclinic orbits leading to chaos.

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**MS18****Onset of Chaos in Singularly Perturbed Systems**

We consider a simple nonlinear system (a nonlinear oscillator) that undergoes a either singular perturbation or a discretization. Generically, the perturbed (discretized) system exhibits a chaotic behavior. For example, a homoclinic or heteroclinic connection do not survive the perturbation. We focus on the following problems: analytical description of breaking of homoclinic connections; breaking of periodic solutions: methods of approximation of perturbed dynamics including stable and unstable manifolds. Theoretically derived approximations are compared with actual dynamics.

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**MS19****Modeling of Smectic A - Nematic Phase Transition**

We develop the point of view that Smectic A liquid crystal configurations are periodic solutions of an extended nematic theory. We identify the physical mechanism responsible for the symmetry breaking of the nematic causing the nucleation of the smectic A phase. We compare the outcome of such modeling approach with the well-known theories of the smectic A-nematic phase transition due to Landau, de Gennes and Lubensky, for both, liquid crystals and superconductors. Flow induced transitions are also addressed.

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**MS19****Viscoelasticity of Solutions of Semi-Flexible Polymers**

Recent work on molecular models of viscoelasticity in solutions of semi-flexible polymers will be discussed. A tube model has been introduced to describe an isotropic 'tightly-entangled' regime in which the polymers are confined to tubes of diameter much less than the persistence length, whose predictions are compared to experiments on solutions of actin protein filaments. Initial results for the linear response of nematic solutions will also be discussed.

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**MS19****Kinetic Models of Polymer-Liquid Crystal Systems**

I will present a kinetic theory for the blend of rigid rod polymers and flexible polymers that account for the Brownian motion, excluded volume and entanglement effects. Solutions in various conditions will be discussed.

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**MS19****Direct Numerical Simulation of Nematic Textures: Phase Transitions and Shearing Flows**

This work will present the computational modeling of nematic liquid crystalline texture that arise during the nematic-isotropic phase transitions and during and after shearing flows. Quantitative descriptions of defect densities, coarsening, global and local orientation correlation functions and light scattering will be presented. The fundamental principles that govern topological processes in defect nucleation and coarsening processes during shearing flows will be presented.

Alejandro Rey

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**MS20****Stabilizing and Destabilizing Effects of Dissipation on Manifolds of Relative Equilibria**

In Hamiltonian systems with symmetries, relative equilibria often come in families, parametrized by the momentum map of the symmetry group. If alongside the Hamiltonian structure also a weak dissipation is present, then, in general, the momentum map is dissipated and the relative equilibria are not preserved, even modulo symmetries. However, the family consists of relative equilibria with different values of the momentum map, so the family can persist. Criteria which determine stability or instability of such persistent families will be given in this talk.

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**MS20****On Relative Normal Modes**

We generalize the Weinstein-Moser theorem on the existence of nonlinear normal modes near an equilibrium of a Hamiltonian system to a theorem on the existence of relative periodic orbits near a relative equilibrium in a Hamiltonian system with continuous symmetries. In particular we prove that under the appropriate hypotheses there exist relative periodic orbits near relative equilibria even when these relative equilibria are singular points of the corresponding moment map, i.e., when the reduced spaces are

singular.

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**MS20****Mechanics on Homogenous Spaces**

When one investigates mechanical systems with symmetry on tangent and cotangent bundles, the group orbits in the configuration space will be immersed homogeneous spaces. Thus a component in the understanding of these systems will be an understanding of mechanical systems whose configuration space is a homogeneous space. In this work we study these latter systems, and our approach is to derive dynamics on a "minimal" smooth manifold (minimal meaning "with small symmetry group").

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**MS20****Bifurcations from Symmetric Relative Equilibria**

Symmetric states play a central role in the analysis of steady motions. The identification of steady motions through a series of symmetry breaking bifurcations from some highly symmetric, and hence easily determined, 'trivial' solutions is a very successful strategy. However, isotropy complicates much of the modern geometric framework for Hamiltonian systems. A 'retro' approach, guided by the modern theory, yields an efficient analysis of systems with and without isotropy, including infinite dimensional problems.

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**MS21****Controlling and Synchronizing Space Time Chaos**

Control and synchronization of extended systems is realized with a finite number of local tiny perturbations, which linearly scales with the size of the system. These perturbations are able to restore each desired unstable patterns, as well as to synchronize two space time chaotic states. The effectiveness and robustness of the method are shown for the amplitude and phase turbulent regimes of the one dimensional Complex Ginzburg Landau equation.

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**MS21****Visualization, Identification and Control of Chaos in Biological Systems**

The identification of chaos in biological and physical systems helps us to understand and possibly control previously intractable problems such as deadly heart arrhythmias (fibrillation) and seizures in the brain. It is the purpose of this talk to introduce the basic tools for understanding, analyzing and controlling chaos in biological systems with an emphasis on the basic principles involved and recent work on controlling atrial fibrillation in humans. Results will also be presented on the high speed, high resolution visualization of ventricular fibrillation in heart experiments.

William L. Ditto

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**MS21****Influence of Noise on Control of Chaotic Lasers**

Experimental studies of control of chaotic lasers showed that control is very difficult to achieve in some operating regimes. We examine time series from different types of laser operation and investigate the influence of noise on the dynamics of the laser [1]. A comparison of experimental results with numerical simulations will be given.

Rajarshi Roy

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**MS21****Nonlinear Prediction, Filtering and Control of Chemical Systems from Time Series**

Advances in controlling dynamical systems, stimulated in recent years by the challenge of chaotic dynamics, have been largely based on the development of linearized models from time series. We present an approach for nonlinear prediction, filtering and control based on the construction of appropriate nonlinear hypersurfaces directly from time-series readings. A three variable model for chemical chaos is used to demonstrate the approach.

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**MS22****Synchronization of Pulse-Coupled Oscillators with Delays**

We show how a synchronized network of integrate-and-fire neural oscillators with non-instantaneous interactions can

destabilize in the strong coupling regime due to a discrete Hopf bifurcation in the firing times. This leads to non-phase-locked behaviour in which the inter spike intervals exhibit periodic or quasiperiodic variations on closed invariant circles. The latter can support several distinct types of behavior including mode-locked bursting states and oscillator death. In the case of a spatially extended network, the invariant circles are separated in phase space resulting in a spatially periodic pattern of mean firing-rate across the network that is modulated by deterministic fluctuations of the instantaneous firing-rate.

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**MS22****Population Coding and Noise Shaping in Spiking Neurons**

Neural information is generally thought to be carried by the firing times of neurons which are often noisy and irregular. If a network of neurons is firing asynchronously, one possible method of encoding analog information into discrete firing times is to consider the average of the population. For uncoupled neurons, averaging will only reduce the noise amplitude by the square root of the number of neurons  $N$ . Borrowing a concept known as noise shaping from electronic analog-to-digital conversion, I will describe a network coupling scheme which can reduce the noise amplitude faster than  $\sqrt{N}$  over a given frequency band.

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**MS22****Dynamics of a Solid-State Laser with Injection**

The mathematical analysis of phase locking in lasers is usually studied in the limit of weak forcing and detuning, where the dynamics reduce to a simple phase equation. But in an intermediate parameter regime, the behavior becomes more subtle. Unlocking occurs via a novel bifurcation scenario that combines supercritical Hopf and saddle-node infinite period bifurcations. This scenario (which probably occurs in other systems) obeys scaling laws that will be explained heuristically.

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**MS22****Small Worlds –The Dynamics of Networks Between Order and Randomness**

The small-world phenomenon is familiar to us through folklore and anecdote – everyone on earth is connected via only a short chain of mutual acquaintances. Here I show that the small-world phenomenon is actually a property of a general class of partly-ordered, partly-random graphs.

These "small-world networks" can be used both to characterize the structure of real networks (as diverse as movie actors, power grids and nervous systems), and also as a framework for exploring the relationship between network structure and the dynamics of distributed systems.

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### MS23

#### Fast Singular Oscillating Limits of Stably Stratified Three-Dimensional Euler-Boussinesq Equations

The 3D rotating Boussinesq equations (the "primitive" equations of geophysical fluid flows) are analyzed in the asymptotic limit of strong stable stratification. The resolution of resonances and a non-standard small divisor problem are the basis for error estimates for such fast singular oscillating limits. Existence on infinite time intervals of regular solutions to the viscous 3D "primitive" equations is proven for initial data in  $H^\alpha$ ,  $\alpha \geq 3/4$ . Existence on a long time interval  $T^*$  of regular solutions to the 3D inviscid equations is proven for initial data in  $H^\alpha$ ,  $\alpha > 5/2$  ( $T^* \rightarrow \infty$  as the Froude number  $\rightarrow 0$ ).

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### MS23

#### On the Algebra of the Curl Operator for Euler and Navier-Stokes Equations

We present new results on the algebra of the *curl* operator for 3D Euler equations and generalized conservation laws. New estimates for solutions of 3D Navier-Stokes equations are derived.

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### MS23

#### Geometric Approximation Methods in Ocean Modeling

A 3D fluid equation for geodesic motion on the diffeomorphism group, with respect to the  $H^1$  metric derived in the framework of the Euler-Poincaré theory, by applying asymptotic expansions, two-timing and averaging, in Hamilton's principle for an ideal incompressible fluid. A new closure model for turbulence in pipes and channels based on a viscous version of this equation. Comparison with experimental data. Applications of this approach in

ocean and atmosphere dynamics.

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### MS24

#### Well Posedness and Ill Posedness for the IVP of Nonlinear Dispersive Equations

In collaboration with Carlos E. Kenig and Luis Vega, we study the problem of the minimal regularity of the data which guarantee that the IVP for some dispersive model are well posed. These models include the 1D cubic (focusing) Schrödinger equation, the KdV and the modified KdV equation. Among other results we prove that the problems are ill posed in Sobolev spaces with index above those suggested by the scaling.

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### MS24

#### The Evolution of Compactly Supported Planar Vorticity

The evolution of ideal incompressible fluid vorticity preserves compactness of support. For planar fluids, the diameter of the support of nonnegative initial vorticity will be shown to grow no faster than  $\mathcal{O}[(t \log t)^{1/4}]$ , improving the bound of  $\mathcal{O}(t^{1/3})$  obtained by Marchioro. In addition, an example of an initial vorticity with indefinite sign will be given whose support grows unboundedly at a rate of  $\mathcal{O}(t)$ .

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### MS24

#### Emergence of Channelized Drainage Patterns and Landsurface Scalings

The evolution of channelized surface flows is characterized

by four phases: initial exponential growth of disturbances; emergent channelized flows; emergent separable solutions with orderly flows; and final dissipation of the surfaces. Polynomial scalings of 0.5 in the autocorrelation functions of water that emerge in the second phase suggest random initial controls while a later scaling of approximately 0.7 in the eroding surface is related to a dynamic scaling condition and transient (similarity) attractors.

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#### MS25

#### Time Reversibility, Entropy Balance, and the Green-Kubo Relations

More than 60 years ago baker maps were introduced by Hopf to illustrate ergodic behavior and the relaxation to thermodynamic equilibrium in closed systems. We generalize these maps to model transport in open systems. The balance equation for the thermodynamic entropy is derived, shedding new light on the notion of reversibility in non-stationary states. Subsequently, fluctuations of the entropy production in steady states are addressed, leading to a novel derivation of the Green-Kubo relations.

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#### MS25

#### Probing the Microscopic Chaos of a Fluid of Particles With a Brownian Test Particle

Experimental evidence for microscopic chaos has recently been reported [P. Gaspard, M. E. Briggs, M. K. Francis, J. V. Sengers, R. W. Gammon, J. R. Dorfman, & R. V. Calabrese, *Nature* **394**, 865 (1998)]. In this experiment, the characterization of Brownian motion has provided a lower bound on the Kolmogorov-Sinai (KS) entropy per unit time of the many-body dynamical system composed of the colloidal particle and of the surrounding water molecules. For this system, the connections between the measured  $n$ -time probabilities, the dynamical entropies, and the spectrum of Lyapunov exponents are discussed.

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#### MS25

#### Hyperbolicity and KAM Bottles in the Driven Lorentz Gas

We study the Lorentz gas with a constant external field and the Gaussian thermostat on a flat torus. In the numerical study of the system, Moran and Hoover (*J. Stat. Phys.* vol. 48, (1987) 709 - 726,) observed that for a strong external field a KAM stable periodic orbit may appear. We show analytically that this cannot happen if  $k+ \langle E, n \rangle \gg 0$  where  $k$  denotes the curvature of a scatterer (it is positive for convex scatterers) and  $n$  is the outer unit normal vector on the boundary of a scatterer. This condition means that to avoid the locking of trajectories in a KAM "bottle" the scatterer must be curved strongly where the field  $E$  points inside it. Where the field points outside, the scatterer can be flat or even concave. We also give explicit conditions under which the system is hyperbolic, i.e. one of the Lyapunov exponents is positive and the other is negative (with respect to any invariant measure).

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#### MS25

#### Multifractal Phase Space Densities for Stationary Nonequilibrium Systems

Computer simulations reveal that the phase space density of a classical system in a nonequilibrium steady state collapses onto a multifractal attractor with an information dimension less than the dimension of the phase space. Such steady states are usually generated by adding energy-constraining forces to the equations of motion, which remain strictly time reversible. However, the phase flow is macroscopically irreversible in accordance with the Second Law. It is shown that the multifractal structure persists if the time-reversible constraint forces are replaced by stochastic boundaries such that the flow is equivalent to a random map.

#### Harald A Posch

#### MS26

#### Embeddings, Fractals and Making Sense of Digital Communications

This paper is about developing new Embedding Techniques which can be applied to digital signal processing. We shall suggest a natural extension of current digital communication channel models to include nonlinearity and reverberation. This leads to stochastic models involving iterated function systems. We shall discuss how time delay methods developed in dynamical systems theory for analysing experimental data can be modified and applied to this kind of channel.

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### MS26

#### Projections, Embedding, and Fractal Dimensions

Think of an “attractor” reconstructed from experimental data as the image of the true attractor for the system under a (probably nonlinear) “projection” from a high- or infinite-dimensional state space to a low-dimensional “embedding space”. What topological and metric properties do the true and reconstructed attractors share? I will discuss conditions under which one can or cannot prove that typical projections between the two spaces are one-to-one and/or preserve the fractal dimension of the attractor.

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### MS26

#### Spurious Lyapunov Exponents in Attractor Reconstruction

Lyapunov exponents are among the most difficult invariants to determine from experimental data. In particular, when using embedding theory to build chaotic attractors in a reconstruction space, extra “spurious” Lyapunov exponents arise that are not Lyapunov exponents of the original system. The origin of these spurious exponents is discussed, and formulas for their determination are given.

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### MS26

#### When Embeddings Perfectly Reflect the Dynamics

I will discuss conditions under which an embedding of a chaotic attractor from data is a diffeomorphism. Previously published conditions only guarantee that the embedding is one-to-one. This is joint work with J. Tempkin and T. Sauer.

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### MS27

#### Stability and Dynamics of Vertically and Horizontally Shaken Sand

Shaking provides a simple mechanism to provide the energy needed to generate and to probe flows of granular materials. Tall layers of vertically shaken sand show a dazzling array of different states. Horizontal shaking results in a simple sloshing mode, plus a novel crosswise convective flow. A combination of both vertical and horizontal shaking provides a way to explore friction models. This talk will explore these aspects of shaking.

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### MS27

#### Wave Patterns in Vertically Oscillated Granular Media

Thin layers of vertically oscillated granular media undergo a bifurcation to patterns of subharmonic standing waves at a critical value of the acceleration amplitude. Depending on the control parameters, squares, stripes, hexagons, or localized states (oscillons) are observed. Stripes undergo secondary crossroll and skew-varicose instabilities. These phenomena are quantitatively reproduced by molecular dynamics simulations, which additionally reveal that the velocity distributions for the grains are Maxwell-Boltzmann, and that convection rolls are driven by the wave motion.

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### MS27

#### Energy Flows, Segregation, and Collapse in Vibrated Granular Media

We study vibrated granular media, investigating each of the three components of the energy flow: particle-particle dissipation, energy input at the vibrating wall, and particle-wall dissipation. Particle-wall interaction is often neglected, but can play an important role when the granular material is dilute. Situations with low agitation and strong dissipation lead to a collapse of the material, the density is rather large, and the observed particle-particle dissipation rate deviates from simple mean-field type predictions.

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### MS28

#### Towards a Variational Principle for the Navier-

**Stokes Equations**

Variational methods represent a unique theoretical tool for producing rigorous inequality results relevant to fluid turbulence. Currently there are two seemingly unrelated approaches for extracting bounds on the energy dissipation in turbulence flows due to Howard & Busse, and Doering & Constantin. I will discuss how these may be interpreted as being *dual* to each other and how their unified whole can be generalised to yield a variational principle for the Navier-Stokes equations.

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**MS28****Scaling and Burning Velocity in Turbulent Combustion**

We investigate and compare the structure of level sets in two turbulent combustion models: reaction-diffusion KPP-type equations and G-equation. It turns out that the structure of the level sets for these two models is significantly different. We use the estimate on the area of level sets for reaction-diffusion equation to obtain a non-rigorous upper bound on the turbulent burning velocity. We also obtain rigorous lower bounds for the burning rate in some situations.

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**MS28****Dynamics and Blowup for an Active Scalar**

We investigate the blowup of radial solutions of the Keller-Segel equations, which model chemotactic aggregation. We find that this system has a rich variety of solutions including multiple steady states, and multiple blowing up solutions that include a countable family of similarity solutions and a non self-similar solution. I will discuss the stability of the various solutions and also present some preliminary results on constructing a global phase-portrait for this system that encompasses all the different behaviors observed.

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**MS28****Energy Dissipation Rate in Shear Driven Turbulence**

We derive rigorous upper bound on the time averaged energy dissipation rate for shear driven turbulence based on the Navier-Stokes model for incompressible fluids. We extend earlier results of Doering and Constantin and obtain upper bound of the form  $\frac{U^3}{L}$  for arbitrary shear driven turbulent flows where  $U$  is the typical length and  $L$  is the typical length of the flow. The upper bound agrees with Kolmogorov's heuristic estimate on energy dissipation rate for turbulent flows. Possible logarithmic corrections to the upper bound will also be discussed.

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**MS29****Phantom Bursting in Pancreatic  $\beta$ -Cells**

In pancreatic islets,  $\beta$ -cells normally produce a bursting pattern of electrical activity with a period of 10-30 sec. However, isolated cells exhibit high-frequency bursting (period 2-5 sec), or low-frequency bursting (period 1-3 min), or do not burst at all. We present a mathematical model that is capable of producing all three types of bursting. Normal islet bursting is produced by the interaction of two slow processes, neither of which has a 10-30 sec time constant, contrary to expectations. This is significant, since no biophysical process has been identified with the "expected" 10-30 sec time constant.

Richard Bertram and Joseph Previte

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**MS29****Adaptation and Synchrony in Neural Oscillators**

There is now good experimental evidence that cortical neurons make the transition from rest to repetitive spiking through a saddle-node bifurcation of a limit cycle. However, it has also been shown that this type of dynamics discourages synchronization between repetitively firing neurons. Most cortical regular spike units have slow currents that cause the firing rate to decrease. In this talk, I will show how these currents alter the synchronization properties of cortical neurons. I will also connect this work with recent results, both theoretical and experimental, on the transition from beta to gamma rhythms in cortical and hippocampal circuits. Bifurcation, formal reduction, and numerical methods will be employed.

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### MS29

#### Neural Excitability, Spiking, and Bursting

We discuss a bifurcational mechanism of generation of action potentials (spikes) by biological neurons. We elaborate Hodgkin's classification and show that neurons from different excitability classes react differently to the same input. Class 1 neurons are always integrators whereas Class 2 neurons may be resonators or filters. We use geometrical bifurcation theory to extend existing classification of bursters to include more than 20 new types.

#### Eugene M. Izhikevich

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### MS29

#### Propagating Activity Patterns in Thalamic Networks

Synaptically coupled neuronal networks can exhibit a wide variety of propagating wave activity. These waves depend on many network properties including whether the coupling is excitatory or inhibitory and the topology of the synaptic footprint. In this talk, I will discuss how geometric singular perturbation methods have been used to determine when the waves exist, compute the wave speed, and determine bifurcations of the waves as parameters are varied.

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### MS30

#### Periodic Orbits in Singularly Perturbed Systems

A general construction of periodic orbits for fast/slow systems due to Soto-Trevino will be described. A new type of "jumping" periodic orbit will be shown to exist in a forced, damped equation modelling the motion of the planet Mercury. The construction uses an adaptation of the Exchange Lemma for tracking invariant manifolds

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### MS30

#### Surface Nucleation of Superconductivity

A superconductor placed in an applied magnetic field will change its state. When the applied field is strong enough, then it penetrates the sample and the material is in the normal state. When the field is reduced to a critical value  $H_{C_3}$  called the upper critical field, the normal state loses

stability and superconductivity nucleates. In this talk we give estimates of the value of  $H_{C_3}(\kappa)$  for a bounded superconductor with arbitrary shape and with large value of the Ginzburg-Landau parameter  $\kappa$ . We also study the location of nucleation and the behavior of the order parameter when the applied field is close to the upper critical field. It is interesting to us that the curvature of the sample plays an important role in the nucleation phenomenon. The results presented in this talk are obtained jointly with Kening Lu at Brigham Young University.

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### MS30

#### On Reaction-Diffusion Systems with Strong Coupling

We consider some reaction-diffusion systems (including Gierer-Meinhardt system and Gray-Scott model) in  $R^2$ . If one diffusion coefficient goes to zero and the other one goes to  $\infty$ , one obtains the so-called shadow system which has been studied by numerous authors. Here we assume one diffusion coefficient goes to zero and the other one is finite. (This is strong coupling case.) We first establish the existence of single and multiple spiky solutions for the stationary system of elliptic equations. Then we show that these solutions are weakly metastable. Finally we consider the motion of two weakly interacting spikes in  $R^2$ .

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### MS30

#### Homoclinic Orbits for Singularly Perturbed NLS

Consider the perturbed NLS

$$iu_t = u_{xx} + 2(|u|^2 - \omega^2)u + i\epsilon(u_{xx} - \alpha u - \beta),$$

where  $u$  is periodic and even in  $x$ . We prove that there exist homoclinic orbits when  $\epsilon > 0$  is small.

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### MS31

#### Levy-Stable Distributions and Self-Similar Teletraffic Modelling

Recent work in teletraffic analysis across a range of network types has provided evidence of statistically self-similar behaviour in the traffic on real networks. This work will report some studies on a variety of teletraffic types, the development of suitable models based on Levy-stable distributions and discuss the impact of such characteristics on call admission control schemes.

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**MS31****Codes for Spread Spectrum Applications Generated With Chaotic Dynamical Systems**

The channels used in digital telephony have the capacity to carry many conversations simultaneously, but if one naively superposes the various signals the result is not simultaneous communication, but babble. The solution is to encode speakers so that their separate voices can later be disentangled. We explain how to construct such codings using an analogy between code-words having desirable correlation properties and time series of measurements from certain dynamical systems—those with Lebesgue spectrum.

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**MS31**  
**Chaos, Communications and Nonlinear Data Analysis**

Potential applications of chaotic dynamics in communication systems are explored. In particular, we discuss the application of nonlinear noise reduction methods for implementing robust information channels. Different noise reduction algorithms are compared which are based on different pre-knowledge about the underlying dynamics. Furthermore, classes of dynamical systems are presented which turned out to be most suitable for applications in communication systems.

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**MS31**  
**Improving the Robustness of Synchronised Chaotic**

**Communication Systems**

Chaotic communication systems potentially offer some advantages over conventional systems. However, while some techniques show some promise, many proposed systems show little, if any, robustness to channel noise and distortion. Bandwidth efficiency is also rarely considered. This is particularly true for self-synchronised systems, and while some methods to compensate for channel distortion exist, they tend to have limited applicability. This paper discusses techniques to improve the robustness of information transmission, while also retaining bandwidth efficiency.

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**MS32****Classifying Excitable Reaction-Diffusion Systems**

The dynamics of extended systems near primary bifurcations can be modelled by amplitude equations. Excitable dynamics cannot be described by such local perturbative theories, yet the ubiquity of some behaviors is an indication that a classification is still possible. In this talk we present a classification of two variable excitable reaction-diffusion systems which is mainly based on the underlying homogeneous dynamics. Some particular applications will also be discussed.

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**MS32****Frequency Locked Patterns in a Periodically Perturbed Reaction-Diffusion System**

Frequency locking has been well studied for driven nonlinear oscillators, yet little is known about the shape and content of the Arnol'd tongues of locking for spatially extended systems. We present experiments which examine the effect of periodic optical perturbations on a light-sensitive oscillatory chemical reaction-diffusion system. Transitions from spiral traveling wave patterns to various frequency locked standing wave patterns are observed. Numerical simulations of a reaction-diffusion model yield qualitatively similar phenomena.

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### MS32

#### Topological Structure of Noise Driven Excitable Systems

It is possible to describe deterministic flows from a topological perspective, studying the organization in phase space of periodic solutions. Noisy excitable systems present complex behaviour, usually studied from a statistical point of view. In this communication we show how to perform a topological analysis of this problem. The extension of the techniques to describe the topology of three dimensional flows to noisy systems allows us also to study higher dimensional deterministic flows.

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### MS32

#### Excitable Behavior in Semiconductor Lasers

We experimentally investigate the dynamical behaviour of semiconductor lasers with feedback. We show that the noise plays an important role close to the instability threshold, anticipating the appearance of a regime called "Low Frequency Fluctuations". We claim that the Andronov bifurcation is at the origin of this dynamical regime.

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### MS33

#### The Motion of The Bubble Towards The Boundary

We establish for the Cahn-Hilliard equation that small bubbles in the interior move towards the closest point on the boundary.

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G. Fusco

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### MS33

#### Multi-Spike Solutions to the Cahn-Hilliard Equation

This represents joint work with Giorgio Fusco. Let  $f$  be a bistable nonlinearity (such as  $u - u^3$ ). We consider multi-peaked stationary solutions to the Cahn-Hilliard equation  $u_t = -\Delta(\epsilon^2 \Delta u + f(u))$  in  $\Omega$ ,  $\frac{\partial u}{\partial n} = \frac{\partial \Delta u}{\partial n} = 0$  on  $\partial\Omega$  with the average value of  $u$  in the metastable region. By "multi-peaked" we mean states which, as  $\epsilon \rightarrow 0$ , tend to a constant value everywhere except for a finite number of points in  $\Omega$ , where the states tend to a different constant value. For any  $N$  we find such solutions with  $N$  peaks located at certain geometrically identified points. The ideas behind the proof come from a dynamical systems approach to PDE's.

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Giorgio Fusco

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### MS33

#### Cascades of Instability in The Solutions of Vector-Valued Cahn-Hilliard Equations

Vector-valued Cahn-Hilliard equations are studied. Simulations of phase separation show two remarkable events. First, the separation proceeds via a cascade of separations, i.e. the one-phase material undergoes separation into a two-phase material which may undergo separation into a three phase material. Second, between the separation events, the two-phase intermediate materials typically coarsen before the third material appears. In this talk, the simulations and an analysis of secondary phase separation will be presented.

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### MS33

#### Pattern Formation in Gradient Systems

The Cahn-Hilliard equation is one of a large class of gradient systems in which stable or metastable patterns arise through the competition between a destabilizing and a stabilizing mechanism. There are many areas of science where such models arise. We examine such a class with the aim of establishing threshold results for the appearance of patterns, as well as some of their properties.

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**MS34****Stochastic Resonance and Neuron Firing; Statistical Aspects**

No information is transmitted by a subthreshold signal. If noise is added, the signal plus noise sometimes exceeds the threshold and information is transmitted, but too much noise decreases detectability. This phenomenon is called stochastic resonance. We explore suitable measures of detectability, compute stochastic resonance surfaces in various parameters, and discuss application to some models of neuron firing. This is joint work with W. Wefelmeyer, U. Siegen, Germany, and L. Ward, Dept. Psychology, UBC.

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**MS34****Current in Sharp Additive Ratchets: Analysis and Exact Results**

We consider a one dimensional stochastic dynamics given by a first order differential equation driven by a telegraph process and standard Gaussian white noise. Such dynamics correspond to the Smoluchowski limit (high damping regime). The deterministic force is derived from a potential which is periodic with sharp barriers of equal height, but nonsymmetric with respect to its extrema. This system exhibits a steady state current,  $J$ , as a result of the asymmetry and the joint effects of the two types of noise. We study the dependence of the current on the diffusion coefficient,  $D$ , and the jump rate,  $\gamma$ , in the entire asymptotic regime of large and small values of these parameters. We find results quite different from those in the case of the smooth potential: here the current depends on fractional powers of the coefficient. We show that  $J$  is not a monotone function of the parameters  $(D, \gamma)$ , and derive an analytical expression for how to maximize the current.

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**MS34****Models and Prediction for Noisy Interface Dynamics**

Metastable interface dynamics are characterized by periods in which the interfaces appear stationary, followed by a rapid transition to a new state. These dynamics can be strongly influenced by small noise. For several applications, we give the stochastic differential equations which model this effect. The time-dependent probability density, which quantitatively describes the dynamics and predicts the transition times, is obtained with a new asymptotic approach.

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**MS34****A Combined Molecular Dynamics and Diffusion Model for Single Proton Conduction Through Gramicidin**

Pomes and Roux have used molecular dynamics to calculate free energies for excess protons and for defects in the hydrogen bonding structure of waters in the pore of the ion channel gramicidin. Together with Pomes and Roux, the author has incorporated these results into a stochastic "framework" model for single proton conduction through gramicidin. Conductances predicted by the model are compared with experiment.

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**MS35****Nekhoroshev-Stability of Elliptic (relative) Equilibria and the Riemann Ellipsoids**

This talk presents some recent results on the classical problem of the stability of elliptic equilibria of Hamiltonian systems and their application to the study of the stability properties of relative equilibria, noticeably the so-called Riemann ellipsoids. The employed approach is based on the methods of Hamiltonian perturbation theory, particularly on Nekhoroshev's theory, which is capable of giving stability results for finite, but extremely long, times.

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**MS35****Stabilization of Relative Equilibria**

This talk will survey two methods of stabilization of relative equilibria in mechanical systems with symmetry. The first, due to Bloch, Leonard, Marsden and Sanchez focusses on modifying the kinetic energy of the system by a Kaluza-Klein construction and is intended for stabilizing balance systems. The second, due to van der Shaft, Marsden and Jalnapurkar, uses potential shaping along with external forces that can change the momentum map. We will propose how these two methods might be synthesized.

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### MS35

#### Drift of Certain 4-vortex Relative Equilibria

Either in the plane or on the sphere, it is possible to arrange a relative equilibrium of 4 point vortices where 3 vortices of strength  $G$  stably rotate around a central vortex of strength of strength  $-3G$  and where the moment of vorticity is zero. Here the symmetry group is  $SE(2)$  in the planar case or  $SE(3)$  in the case of the sphere; either way, zero is a nongeneric value for the momentum mapping and if perturbed these relative equilibria move about the plane or sphere. This talk will present aspects of the theory and numerics of this dynamics.

George W. Patrick

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### MS35

#### A Generalization of Riemann's Theorem for Rotating Fluid Masses

This talk will describe joint work with Esmeralda Sousa Dias which generalises Riemann's theorem for the angular momentum and circulation vectors of an ellipsoidal relative equilibrium of a rotating fluid mass to sufficiently symmetric relative equilibria of any simple mechanical system with  $SO(3) \times SO(3)$  symmetry. In particular we show that some 'pear-shaped' relative equilibria of rotating fluid masses satisfy the generalised theorem.

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### MS36

#### From Generalized Synchrony to Topological Decoherence: The Decoherence Bifurcation

Transitions that occur as coupled systems are decoupled have been described in the literature in terms of the dynamics on the synchronization manifold. We describe a new transition, which we call the decoherence bifurcation, that is characterized by the creation of complicated sets off of the synchronization manifold. The proposed framework is applicable to non-identical coupled systems where symmetries are absent. We describe the transition and its dynamical consequences in several examples.

Ernest Barreto and Paul So

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### MS36

#### Dynamics of Coding in Communicating with Chaos

A well chosen grammar leads to trajectories that live on a nonattracting but noise-resisting chaotic saddle embedded in a chaotic attractor. We find that the topological entropy of these chaotic saddles typically have a devil-staircase like behavior as a function of the noise resisting strength. Fur-

thermore, there is usually a range of noise resistance in which the topological entropy decreases only slightly from that of the full chaotic attractor. The implication is that digital communication using chaos can yield a substantial channel capacity even in noisy environment.

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### MS36

#### Calculating Topological Entropy with an Application to Communicating with Chaos

Motivated by recent work on communicating with chaos, we discuss numerical methods for evaluating the topological entropy of chaotic invariant sets, and in particular, invariant chaotic saddles formed by those points in a given attractor that never visit a forbidden gap region. Such gaps have been proposed as a means of providing noise immunity in schemes for communicating with chaos, and we discuss the dependence of the topological entropy on the size of the gap.

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Institute for Physical Science and Technology  
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### MS36

#### Box-counting Dimension Without Boxes: Calculating $D_0$ from Average Expansion Rates

We propose an iterative scheme for calculating the box-counting (capacity) dimension of a chaotic attractor in terms of its average expansion rates. Similar to the Kaplan-Yorke conjecture for the information dimension, this scheme provides a connection between a geometric property of a strange set and its underlying dynamical properties. Our conjecture is demonstrated analytically with an exactly solvable two dimensional hyperbolic map and numerically with a more complicated higher dimensional non-hyperbolic map.

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### MS37

#### Extended Geostrophic Euler-Poincaré Ocean Models

We consider the motion of a rotating, continuously stratified fluid governed by the hydrostatic primitive equations. Approximate Euler-Poincaré models (L1 and L2) for small Rossby number are derived for application to mesoscale oceanographic flow problems. Results of numerical experiments involving a baroclinically unstable oceanic jet show that the new L1 and L2 models give accurate solutions with errors substantially smaller than other balanced models.

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### MS37

#### Dynamical Systems Challenges in Assessing Ocean Transport

Recent developments in dynamical systems have afforded the application of geometric techniques to strongly time-dependent flows. These techniques can be used to determine the redistribution of fluid around coherent features, such as jets and eddies. Discussed will be joint work with Pratt and Miller on a study of circulation around an island. The fluid transport, and resulting vorticity budgets, associated with the dead zone off the eastern coast of the island will be determined. This will lead into a general discussion of the role of (eddy) viscosity, which is commonly used in (numerical) ocean models, in promoting transport of fluid particles and the implications for the transport of potential vorticity.

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### MS37

#### Successive Bifurcations in the Oceans' Wind-driven Circulation

The large-scale flow of the mid-latitude oceans is dominated by the presence of a larger, anticyclonic and a smaller, cyclonic gyre. The two gyres share the eastward extension of western boundary currents, such as the **Gulf Stream or Kuroshio**, and are induced by the shear in the winds that cross the respective ocean basins. The boundary currents and eastward jets carry substantial amounts of heat and momentum; the jets also contribute to mixing in the oceans by their "whiplashing" oscillations and the detachment of eddies from them. The low-frequency variability of this double-gyre circulation, for time-constant and purely periodic wind stress, is studied by the methods of nonlinear dynamics, analytically and numerically. **Symmetry-breaking bifurcations** occur, from steady to periodic and aperiodic flows, as wind stress increases or dissipation decreases. The first bifurcation is of pitchfork or perturbed-pitchfork type, depending on the model's degree of realism. Two types of oscillatory instabilities arise by supercritical **Hopf bifurcation**, with periods of a few months and a few years, respectively. Numerical evidence points to hetero- and homoclinic orbits that connect high- and low-energy branches of steady-state solutions. The results are compared with decade-long in situ and more recent, satellite observations of three ocean basins, the North and South Atlantic, and the North Pacific, and their significance for climate variability is discussed. This talk reflects collaborative work with K.-I. Chang (KORDI), H. Dijkstra (Utrecht), Y. Feliks (IIBR, Israel), K. Ide (UCLA), S. Jiang (MIT), F.-f. Jin (U. Hawaii), C. A. Lai (LANL), G. Loepke (ENS, Paris), Z.-g. Pan (UCLA), E. Simonnet (Paris Sud/Orsay), S. Speich (UBO/Ifremer, Brest), R. Tmam (Indiana U. & Orsay), & S. Wang (Indi-

### MS37

#### Material Dispersion in Wind-driven Ocean Gyre

The prevailing winds on Earth drive basin-filling oceanic gyres in between the continents. These gyres are spatially inhomogeneous and turbulent. To characterize movement of matter in gyres, we integrate parcel trajectory equations,  $\dot{\mathbf{x}}(t) = \mathbf{u}(\mathbf{x}, t)$  for an ensemble of initial placements, given a solution for  $\mathbf{u}(\mathbf{x}, t)$ . As a simpler alternative characterization, we assess the useful sill in an inhomogeneous, non-stationary stochastic trajectory model.

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### MS38

#### Nonsmooth Bifurcations, Sliding Orbits and Their Application in Piecewise Smooth Dynamical Systems

We will discuss the role played by nonstandard bifurcations and other non-smooth phenomena in organising the dynamics of piecewise smooth systems. We will focus our attention to the occurrence of so-called border-collision and grazing bifurcations. After discussing a possible classification strategy, we will show how these bifurcations can lead to the formation of periodic orbits characterised by *sliding* sections (lying partly within the system discontinuity set). These orbits will be shown to organise "double-spiral" bifurcation diagrams describing the accumulation of periodic solutions, characterised by different number of switchings, onto a central sliding orbit. Applications to systems of

relevance in Engineering will be presented.

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**Chris J Budd**  
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### MS38

#### Graph Theory, Probability and Many Dimensional Piecewise Smooth Dynamical Systems

In this paper we present a new method for the analysis of general piecewise smooth dynamical systems of arbitrary dimension, with particular reference to a model of impact dynamics in heat exchangers. We propose a hybrid method, linking graph theory and probability theory. This method enables us to classify and enumerate periodic solutions, construct a basis for the space of periodic solutions and to predict the exact nature of these solutions. Moreover, we are able to model the behaviour of the system as parameters are changed, and to show good agreement with experiments and numerical simulations.

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### MS38

#### Analysis of Grazing Bifurcations in a Continuous and Piecewise Differentiable Friction Model

We investigate a recently proposed model of macroscopic friction, where the vector field is continuous, but has discontinuous derivatives across a border in state space. Several instances of localized bifurcation sequences are connected with near-grazing periodic orbits. We analyze these using *discontinuity mappings*. The results obtained show similarities with impacting systems, and are quite general for systems with a discontinuous first derivative in the limit of large discontinuity.

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### MS38

#### Describing the Bifurcations of Piecewise Smooth Systems

Bifurcations of piecewise smooth dynamical systems can be studied via a type of linearization; that is, a piecewise linear map, such as a tent map in dimension 1. I will discuss the bifurcations that Helena E. Nusse and I observe for two-dimensional piecewise linear systems.

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### MS39

#### Multifractal Spectra and Eigenfunction: What Determines the (Anomalous) Spreading of Wave Packets?

There is a variety of different quantum mechanical systems which exhibit multifractal spectra and/or eigenfunctions, including e.g. quasiperiodic Schrödinger equations, disordered systems and quantum Hall systems. It has been a question for quite some time, what generally determines the decay of correlations and the spreading of wave packets, that are found in numerical investigations. We show that for the class of systems which preserve the shape of the wave packet, its width increases as a power law in time. The exponent is given by the ratio of two multifractal dimensions, the dimension  $D_2$  of the energy spectrum, divided by the dimension  $D_2$  of the eigenfunctions. For the general case we show that this ratio is an optimum lower bound for the spreading exponent. Numerical results will be presented to illustrate these general results.

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### MS39

#### Dynamics with Singular Continuous Spectra: Mechanisms and Renormalization Group Description

A short overview of spectral properties of dynamical systems with special emphasize on singular continuous spectra is given. Basic models demonstrating fractal spectra in dissipative systems (strange nonchaotic attractors) as well as in quantum mechanics (quasiperiodically driven spin-1/2 system) are described, and self-similar features of correlations and spectra are demonstrated. We show, how these self-similarities can be quantitatively described with the renormalization techniques based on symbolic description

of the process.

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**MS39**

**Hidden Dimer in the Frenkel-Kontorova Model: Extended, Critical and Localized States in Quasiperiodic System with an Infinite Number of Steps**

The incommensurability of the supercritical Frenkel-Kontorova model is decomposed into a family of *dimer* type "defects". The linear excitations of the system are then described by a tight binding quasiperiodic system with an infinite number of steps. The system exhibits resonance transitions where the *critical* fractal states of the model degenerate to the Bloch-type waves. In a generalized two-parameter model, the model exhibits localized states where the localization boundary interwines with the resonance transitions. In contrast to the rigorous results on the absence of localization in discrete quasiperiodic potential with *finite* number of steps, our study shows localization in a discrete quasiperiodic potential with an *infinite* number of steps.

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**MS39**

**Dissipative And Hamiltonian Dynamics With Fractal Fourier Spectra: Symbolic Description And Multifractality**

We discuss dynamical systems with singular continuous Fourier spectra: dissipative flows whose attractors contain saddle points, and Hamiltonian systems which describe steady planar flows of viscous fluids past arrays of eddies or solid obstacles. In both cases onset of fractal spectra is caused by singularities in the return (passage) times of the orbits. We provide a description of this phenomenon by means of self-similar symbolic sequences. A technique is proposed which yields exact values for certain generalized dimensions of multifractal spectral measures.

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**MS40**

**Libration Orbit Missions: Historical Perspective and Future Applications**

The Goddard Space Flight Center is at the cutting edge of technologies that support libration orbit mission design. Advances in mission design using invariant manifold theory, state-space equations for libration orbit control, and optimization based on eigenvector formulation to achieve constrained orbit parameters is discussed. A brief history detailing various missions — ISEE-3, WIND, SOHO, and ACE — is provided. These requirements are compared to those of upcoming missions like MAP, NGST and TRIANA.

David Folta

Goddard Space Flight Center

**MS40**

**Tools to Explore Liberation Point Orbits**

Analytical and numerical tools to understand the phase space around the collinear libration points L1 and L2 are presented. The results given in terms of Poincaré sections and semianalytical expansions are presented for simplified models of the Sun-Earth and Earth-Moon systems. The role of the stable and unstable manifolds of the objects in the center manifold for transfer problems (from Earth to libration orbit, and between libration orbits) and for station keeping strategies are shown.

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**MS40**

**Heteroclinic Connections and Resonance Transitions in Celestial Mechanics**

We apply dynamical systems techniques to the problem of heteroclinic connections and resonant transitions in the restricted three-body problem. These phenomena have been of concern to areas such as resonant capture of comets and trajectory design for newer missions, like Genesis. We show that the invariant manifold structures associated to libration points  $L_1$ ,  $L_2$  and the heteroclinic connections between their Liapunov orbits are fundamental tools that aid in understanding dynamical channels throughout the solar system.

Wang Sang Koon

Control and Dynamical Systems  
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**MS40**

**From Genesis to Armageddon**

Genesis will be NASA's first mission to launch in the new millennium. It is also the first mission designed with dynamical systems theory, using the L1-L2 heteroclinic dynamics. The same dynamics contributes to the puzzling temporary-capture phenomenon of Jupiter comets, the famous groups and gaps in the Asteroid Belt, and the Near Earth Asteroid problem. This rich dynamics will enable new mission concepts like the New Grand Tour using the

symbolic dynamics of L1 and L2.

Martin W. Lo

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**MS41**

**Periodic Orbits in Re-Entrant Manufacturing Systems**

Queue changes associated with each step of a manufacturing system are modeled by constant vector fields (flow models). A Poincare map reduces these vector fields to a set of piecewise linear maps. It is proved that these maps show only periodic or eventually periodic orbits. An algorithm to determine the period of the orbits is discussed. The dependence of the period on the processing rates is shown for a 2-machine-4-step problem.

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**MS41**

**On the Optimal Scheduling for Warehouses**

We apply the ideas of "bucket brigade" production lines to the problem of optimal sequencing of pickers in warehouses. The warehouse model is by necessity stochastic one because the orders of customers are random. nevertheless the knowledge of deterministic dynamics of the corresponding production lines, which appear when the probability to order each item equals one, allowed to essentially increase pick rate.

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**MS41**

**Stability of Queueing and Fluid Reentrant Networks**

Evaluating the stability of reentrant queueing networks under various scheduling rules has proved to be a particularly interesting and challenging problem. Significant advances have been made in the last decade by demonstrating a close connection between the stability of the stochastic model and its continuous deterministic analog, a so-called fluid model. We present recent results demonstrating the subtle connection between the two models and review the techniques used to successfully analyze the stability of fluid networks.

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**MS41**

**A Dynamical Systems Analysis of a Periodic Client-Server Network**

We investigate a periodic client server network using a dynamical systems approach. The network consists of n processors, linked to a central server which has a queue of size n-1. We consider the service protocols First In First Out (FIFO) and Last In First Out (LIFO) with 2 and 3 clients with periodic requests to be serviced. For the FIFO case we present formulas to compute efficiency of the system as well as sufficient conditions for no waiting in the queue. For the LIFO case we characterize the behavior of the system.

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**MS42**

**Front Dynamics in a Spatially Discrete System**

In many spatially continuous, nonlinear systems the dynamics focusses on coherent structures such as solitary waves or localized fronts that separate homogeneous equilibrium phases. Here we explore the dynamics of coherent structures in spatially discrete systems. Systems of this kind arise in lattice dynamics and in theory of chains of coupled nonlinear oscillators. Notably, we consider the stability of pulses and fronts using a version of the Evans function technique. This method allows us to uncover bifurcations from the continuous spectrum for structures on infinitely long chains and lattices.

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**MS42**

**Existence and Stability of Dark Solitons**

The stability of the dark soliton solution to a Ginzburg-Landau perturbation of the defocusing nonlinear Schrödinger equation (NLS) is considered. As an application of dynamical systems techniques, it is shown that the dark soliton can persist as either a regular perturba-

tion or a singular perturbation of that which exists for the NLS. When considering the stability of the perturbed soliton, a major difficulty which must be overcome is the location of eigenvalues which bifurcate out of the continuous spectrum. Since the continuous spectrum for the NLS covers the imaginary axis, such a bifurcation may lead to an unstable wave. When the wave persists as a regular perturbation, it is shown that at most three eigenvalues will bifurcate out of the continuous spectrum. Furthermore, the location of these eigenvalues is tracked precisely, thus leading to a stability criteria. The results are an improvement and refinement of previous studies in which either a variational analysis or an adiabatic analysis were used. Furthermore, the methods used to achieve the results are general and applicable to a wide class of problems.

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#### MS42 **Essential Instability of Pulses and Bifurcation to Modulated Travelling Waves**

We study pulses and fronts for reaction-diffusion systems on the real line. Various instability mechanisms which involve the essential spectrum are analyzed: the asymptotic state of the travelling wave solution destabilizes, for example via a Turing instability. We prove existence and stability of bifurcating modulated travelling waves.

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#### MS43 **Geometrical Analysis on the Intracellular Calcium Wave Propagation**

We study a two pool model proposed by Goldbeter for intracellular calcium wave propagation by calcium-induced calcium release with attention on the dispersion relations of the periodic traveling wave trains. The temporal behavior of the model can be understood by analogy with FHN dynamics. We consider a more general model with diffusion than the piecewise linear model. By the singular perturbation method we derive a singular equation which behaves like a generic excitable system, fast and slow dynamics are distinct. For a given background  $IP_3$  concentration we show how the dispersion curves begin and which periodic waves are stable.

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#### MS43

#### **The Spatial Distribution of IP<sub>3</sub> Receptors and the Dynamics of Intracellular Calcium**

We analyze the effect of the spatial distribution of IP<sub>3</sub> receptor/Ca<sup>2+</sup> channels on the dynamics of intra-cellular calcium. We consider a model of calcium release from the endoplasmic reticulum that describes the emission of calcium from spatially discrete channels and its subsequent continuous diffusion and uptake back into the endoplasmic reticulum. We demonstrate that the discreteness of the release sites can have a dramatic effect on the dynamics of intracellular calcium.

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Silvina Ponce Dawson  
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#### MS43

#### **Elementary events of Intracellular Calcium Signaling**

Intracellular Ca<sup>2+</sup> liberation through IP-3- and ryanodine-receptor/channels occurs discontinuously as 'elementary' release events (puffs and sparks), that arise at clusters of channels forming discrete release sites. Individual sites can generate autonomous, transient events involving single or multiple channels, and their activity may be coordinated by Ca<sup>2+</sup> diffusion and Ca<sup>2+</sup>-induced Ca<sup>2+</sup> release to propagate global Ca<sup>2+</sup> waves. We are studying mechanisms underlying generation of Ca<sup>2+</sup> puffs in Xenopus oocytes, and the ways in which Ca<sup>2+</sup> diffusion and the spatial arrangement of release sites interact to initiate and propagate waves.

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#### MS43

#### **Calcium Dynamics in Astrocytes**

Intercellular calcium waves in astrocytes have been shown to influence neuronal communication in the central nervous system and may play a role in disorders such as epilepsy. Experiments indicate the calcium dynamics may be mediated by an extracellular messenger via a G-protein linked signal transduction pathway. In this work we derive and analyze a model of calcium dynamics which includes the influence of an extracellular messenger. We examine the influence of the extracellular messenger on both the local calcium dynamics and intercellular calcium waves.

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#### **MS44**

#### **Attractors, Chain Transitive sets and Invariant Measures**

Given a finite dimensional map of a compact space  $X$  to itself, we study the Markov chain approximation of the map based on a partition of  $X$ . Assuming the map is continuous, approximations of chain transitive sets and stable attractors are constructed. Using the work of Buescu and Stewart, we will show that the procedure also yields approximations to the SBR measure of a class of transitive Lyapunov stable attractors.

#### Fern Hunt

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#### **MS44**

#### **Stability of Attractors in Forced Systems**

Dynamically invariant submanifolds arise in a variety of contexts, particularly in the area of chaotic synchronisation and its use in communication systems. A common model for such systems is a skew-product of the form  $T(x, y) = (f(x), g(x, y))$  in which  $f$  is an ergodic map of a compact metric space  $(X, \mu)$  and  $g : X \rightarrow R^n$  is a Lipschitz map with negative Lyapunov exponents in the fiber  $R^n$ . We study the stability of attractors in such skew-products under deterministic and random perturbation of  $g$ .

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#### **MS44**

#### **Graphs and the Stability of Stochastically Forced Systems**

We describe a framework for the study of the stability of stochastically forced systems. We discuss the significance of invariant graphs in this context and their relationship to invariant measures. We analyse to what extent Liapunov exponents give sufficient conditions for the existence of such graphs and present recent results on their regularity. We explain the relevance of these to dimension increase in recursive filters and to the stability of chaotic synchronization to noise.

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#### **MS45**

#### **A Nonlinear Analysis of the Averaged Euler Equations**

This talk will survey some of the recent work (with Shkoller, Ratiu, Holm, and Kouranbayeva) on the anal-

ysis of the averaged Euler equations. We will begin with a motivational derivation of the equations. Then we show how they may be regarded as geodesics for the  $H^1$  metric on the volume preserving diffeomorphism group, as Arnold did for the Euler equations. Then we will present some of the analytical theorems, as in Ebin and Marsden, including the convergence as viscosity tends to zero in the presence of boundaries. We will also briefly indicate some of the computational aspects of the equations.

#### Jerrold E. Marsden

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#### **MS45**

#### **The SU(n) Approximation to the 2D Averaged Euler Equations**

It is now well known that the Poisson bracket on  $\text{su}(n)$  converges to the Poisson bracket on Lie algebra of all smooth divergence free vectors on the flat two torus. This suggests that  $\text{SU}(n)$  is a discretization of the area preserving diffeomorphisms of the two torus. We shall discuss numerical simulations in which the  $\text{SU}(n)$  discretization is used to approximate solutions to the averaged Euler equations. Unlike the usual pseudo-spectral codes that conserve only energy and the first Casimir, this discretization scheme is able to conserve the first  $n-1$  Casimirs.

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#### **MS45**

#### **Geometry and curvature of new diffeomorphism groups and the averaged Euler equations**

This talk will focus on the geometry of the averaged Euler equations, a system of PDEs whose solutions correspond to the ensemble averaged component of the solutions of the Euler equations. I shall describe new diffeomorphism groups whose geodesics are the solutions to the averaged Euler equations, computations of the sectional curvature of these groups, and new sets of boundary conditions that give rise to regular limits of zero viscosity.

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#### **MS45**

#### **New Pressure Estimates for the 2D Euler Equation**

Using new elliptic regularity results for Jacobian determinants in Hardy spaces, we are able to improve the classical estimates on the pressure function in the two dimensional Euler equations of ideal hydrodynamics.

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**MS46****Modelling Multistable Systems**

Dynamical processes in nature often possess a multitude of different stable long-term behaviors (attractors) for a given parameter set. Under the influence of noise, the dynamics of such systems consists of regular phases of motion in the neighborhood of attractors and chaotic phases of motion on the complexly interwoven basin boundaries. We show how this hopping process between different attractors can be characterized and discuss the implications on the detection of multistability from observed data.

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numerically in a nonparametric way calculating optimal transformations, a concept of nonlinear regression analysis. For delayed-feedback systems, the delay times and the governing delay-differential equations can be estimated well. We demonstrate the applicability of the method on numerical examples and on experimental data from a ring cavity laser experiment.

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**MS47****Complex Spatio-Temporal Dynamics of Neural Networks**

We review our recent studies on complex spatio-temporal dynamics of neural network models composed of neurons with chaotic dynamics or coincidence detector neurons, which are derived on the basis of properties of real neurons. We analyse various spatio-temporal dynamics of the models from the viewpoints of not only artificial neurocomputing but also dynamical information processing in the brain. We also consider possible relationship between the model behaviour and physiological data experimentally observed.

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**MS46****Obstruction To Modelling**

I will analyze a new level of mathematical difficulty, brought from the theory of dynamical systems, that can limit our ability to represent nature using deterministic models. Specifically, I will show that certain chaotic systems found in nature cannot be modelled using evolution equations. No model of such a system produces solutions that are realized by nature.

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**MS47****Detection of n:m Phase Synchronization from Noisy Data**

We use the concept of phase synchronization for the analysis of noisy nonstationary bivariate data. Phase synchronization is understood in a statistical sense as an existence of preferred values of the phase difference. Two techniques are proposed for a reliable detection of synchronous epochs. These methods are applied to several neurophysiological data.

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**MS47****Synchronization of the Stochastic Dynamics of Paddlefish Electroreceptor Cells**

Stochastic synchronization of the noisy internal oscillators of the electroreceptor cells in paddlefish, *Polyodon spathula*, with external periodic stimuli is studied in electrophysiological experiments. We find episodes wherein the responses are phase locked to the stimulus separated by periods of phase slippage. The length and times of these occurrences are random numbers. The experimental data are

**MS46****Reconstruction of High-Dimensional Nonlinear Models from Data**

We analyze data from high-dimensional dynamical systems, like delayed-feedback and spatially extended systems, using a suitable optimization problem. It is solved

well described by a noise mediated Hodgkin-Huxley model and by a stochastic circle map.

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#### MS47

##### Phase Locked Brain Activity in the Motor System

We developed a new method which makes it possible to detect  $n : m$  phase synchronization in noisy nonstationary data [Tass et al., Phys. Rev. Lett. 81 (1998) 3291ff]. We applied our method to multichannel whole-head MEG (magnetoencephalography) data and related signals such as EMG (electromyogram) registered in parallel. Our single run analysis reveals characteristic cerebral synchronization processes that reflect movement coordination and different types of motor control observed under physiological and pathological conditions.

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#### MS48

##### Mixing and Diffusion in Aperiodic Flows

The dynamical systems theory of Lagrangian mixing offers a framework in which to study transport in two-dimensional vector fields with regular time-dependence. While the theory has been successful in the analysis of periodic or quasi-periodic flows, it fails for flows with general time dependence. In this talk we discuss a geometric theory of mixing for aperiodic fields. The velocity field is assumed to be given numerically or experimentally on a finite grid for a finite time. We describe computer assisted analytic results that identify finite-time hyperbolic structures in the flow. Applications to ocean dynamics as well as the relevance of finite-time invariant manifolds to the transport of active scalars will be discussed.

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#### MS48

##### The Fractal Nature of Vorticity at High Reynolds Number

We consider a smooth Lagrangian chaotic fluid flow at high Reynolds number. It is shown that the smooth flow is unstable to the generation of small scales in which vorticity concentrates on a fractal and has an associated multifractal measure. The possible significance of this result for fully developed turbulence is discussed.

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#### MS48

##### Indecomposable Continua in Fluid Flow Past an Array of Cylinders

Fractal structures appear naturally in nonlinear dynamical systems. These structures are invariant sets and are unchanged under the time evolution of the dynamical system. Many fractal sets in dynamics can be classified topologically as being indecomposable continua. The invariant fractal sets formed in the wake of cylinders of fluid flow past an array of cylinders are shown and some properties of indecomposable continua are used to prove their persistence under the influence of a small amount of noise.

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#### MS48

##### Advection in Chaotically Time-Dependent Open Flows

The passive advection of tracer particles is considered in open two-dimensional incompressible flows with chaotic time-dependence. As illustrative examples we investigate flows produced by chaotically moving ideal point-vortices. The advection problem can be seen as a chaotic scattering process in a chaotically driven Hamiltonian system. Studying the motion of tracer ensembles, we present numerical evidence for the existence of a bounded chaotic set containing infinitely many aperiodic trajectories never leaving the mixing region of the flow. These ensembles converge to filamental patterns which, however, do not follow self-similar scaling. Nevertheless, they possess a fractal dimension after averaging over several finite time realizations of the flow. We propose random maps as simple models of the phenomenon.

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#### MS49

##### Nonlinear Modal Interactions in a Kicked Flexible

**Rod**

The Karhunen-Loeve (K-L) decomposition is used experimentally to study modal interactions in a flexible steel rod "kicked" by a spatially triggered electromagnet. Two specific nonlinear modes are shown to interact in the observed dynamics over a wide range of the magnet voltage  $V$ . As  $V$  increases, a sequence of bifurcations into distinct dynamical regimes is observed: small amplitude limit cycle; quasiperiodic response; chaos; and large amplitude limit cycle. Experimental results are compared to a theoretical model developed with the aid of the K-L data.

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**MS49****POD Analysis of the Interaction Dynamics of Coupled Systems in Continuum Mechanics**

The POD method is used to analyze the interaction dynamics in coupled mechanical systems consisting of linear continua coupled to nonlinear oscillators. It is found that the linear continuum and nonlinear oscillators interact to produce regular and chaotic motions containing slow and fast time scales observed in the weak coupling limit. This work reveals the role the reduced slow and fast motions of the weakly coupled system play in the creation of the interaction dynamics.

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**MS49****Exponential Attractors and Inertial Dynamical Systems in Continuum Mechanics**

Exponential Attractors are positively invariant sets, with finite fractal dimension which attract uniformly exponentially all trajectories. We demonstrate their existence in a general context of semiflows in Banach spaces which admit an absorbing ball and are uniformly differentiable therein. The only requirement is for the linearized semiflow to be the sum of a compact plus contraction operator. Applications are made for dispersive viscoelasticity models with Korteweg capillarity. Equivalent inertial dynamical systems are constructed.

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**MS49****Nonlinear Normal Modes in a System with Non-****holonomic Constraints**

Nonlinear normal modes are periodic motions in a multi-degree of freedom system defined to be vibrations-in-unison. These have been investigated in holonomic systems since the 1950's. The present work extends these ideas to systems with nonholonomic constraints. We investigate the dynamics of a system involving the planar motion of a rigid body which is restrained by linear springs and which possesses a skate-like nonholonomic constraint known as Caplygin's sleigh. Second order averaging is used. 1:1 internal resonance is investigated.

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**MS50****Exchange Lemmas for Singularly Perturbed Problems Certain Turning Points**

Singular perturbation problems with certain type of turning points are studied from a geometric point of view. Based on the local property of the turning points initially studied by Pontryagin and the center manifold theory for invariant manifolds developed by S.-N. Chow, W. Liu and Y. Yi, we extend the Exchange Lemma first formulated by Jones and Kopell for normally hyperbolic slow manifolds to the ones with such type of turning points. Applications to various boundary value problems will also be discussed.

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**MS50****Invariant Manifolds and Foliations for Infinite Dimensional Dynamical Systems**

When considering the question of persistence of invariant manifolds for a dynamical system when that system is perturbed, one is naturally led to the concept of normal hyperbolicity. Roughly speaking, this requires that the tangent bundle of the phase space, restricted to the manifold, splits into three subbundles, one of which is the tangent bundle of the manifold and the linearized flow either expands or contracts the other bundles at rates greater than any expansion or contraction in the tangent bundle. In this talk, we shall report our recent works on normally hyperbolic invariant manifolds, especially, overflowing manifolds for infinite dimensional dynamical systems. We do not assume that the manifolds are compact or finite dimensional. The manifolds are not necessarily imbedded manifolds, but immersed manifolds. The existence of invariant foliations will also be given. We should mention that the infinite dimensional dynamical systems generated by, for example, parabolic equations are not reversible and the phase spaces are not locally compact. This characteristic creates difficulties not encountered in the study of finite dimensional dynamical systems and new methods need to be developed to understand the nature of these systems. This is joint work with Peter Bates and Chongchun Zeng.

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### MS50

#### Dynamics of Electronic Oscillators

Early vacuum tube oscillators had their theory in the form of van der Pol equation. Ironically during last 60 years this equation became better known in ODE's than in Electrical Engineering. In the former it contributed to the theory of averaging and integral manifolds and gave rise to Smale's horseshoe, in the latter it became virtually forgotten. This paper aims at bringing the two worlds together. It reviews engineering needs and design methods and compares them with oscillations theory. Common goals as well as different approaches are discussed with the emphasis on possibilities of combining theory and design.

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### MS51

#### Four States of Motion Unique to the Dynamics of Cellular Flames

This talk will present the characteristics of four states of cellular flames with unique dynamics. In hopping states individual cells abruptly change their angular position in a sequential manner. Ordered states exhibit an intrinsic chaotic wiggling in 2-D patterns but not in 1-D lines of cells. In intermittently ordered states patterns of concentric rings of cells appear and disappear at irregular intervals. Ratcheting states correspond to very slow, nonuniform rotations of one or more rings of cells.

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### MS51

#### Interaction of Counterpropagating Hot Spots in Solid Fuel Combustion

We consider combustion waves propagating along a cylindrical solid fuel sample, describing the Self Propagating High Temperature Synthesis process to synthesize advanced materials. There exist spinning modes of propagation, characterized by hot spots (localized high temperature pulses) which rotate around the sample as they propagate, thus following a helical path on the cylinder. We analyze interacting counterpropagating hot spots, thus describing the phenomena of apparent annihilation and creation of hot spots, recently observed in experiments.

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### MS51

#### Nonlinear Dynamics in Frontal Polymerization

Frontal polymerization (FP) is a mode of converting monomer into polymer via a localized reaction zone that propagates. The conditions for existence of free-radical FP are considered. Convective and thermal instabilities pose serious challenges to commercialization, and the results of sounding rocket and parabolic airplane flights will be discussed. Special consideration will be given to spin mode instabilities and the similarities and differences to phenomena observed in Self-Propagating High Temperature Synthesis.

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### MS51

#### Mathematical Modeling of Frontal Polymerization

Frontal polymerization (FP) is a process in which a localized reaction zone propagates into a monomer, converting it into a polymer. The process is currently under investigation as a novel method to produce polymers. Mathematical models of FP involve highly nonlinear interactions between chemical kinetics and heat/mass transfer processes. We develop a mathematical model of FP and determine the structure of the polymerization wave, its propagation velocity and their dependence on the problem parameters.

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### MS52

#### Computation of Lyapunov Exponents via Spatial Integration with Application to Blowout Bifurcations

We describe a new method for approximating the largest Lyapunov exponent which is found as the limit of a sequence of integrals with respect to the invariant measure. The integrals may involve either a matrix norm or a vector norm. This approach requires much less computation than a long term simulation of a dynamical system for the detection of blowout bifurcations in coupled systems. The new method is illustrated for two coupled Duffing oscillators.

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**MS52****The Numerical Computation of Rigorous Coverings for Invariant Manifolds**

We present robust techniques for the numerical approximation of (multidimensional) invariant manifolds. These methods rely on a multilevel subdivision procedure for box coverings which gives convergence on compact subsets. Additionally, we can construct rigorous coverings using Lipschitz estimates. As an example we present a covering of a two-dimensional unstable manifold of a periodic orbit in the circular restricted three body problem. This result is of potential interest for the design of spacecraft missions.

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**MS52****Symbolic Dynamics for Time Series**

Using data obtained from a magnetoelastic ribbon experiment we show how a new approach based on topological techniques can be used to obtain a description of the dynamics in terms of subshift dynamics on a finite set of symbols. These topological methods have been developed in a way that allows for the inclusion of experimental error and the existence of bounded noise.

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**MS52**  
**Numerical Approximation of Random Attractors**

We will present an algorithm (based on the subdivision algorithm of Dellnitz and Hohmann) for the numerical approximation of attractors for random dynamical systems, which serve as a model for dynamics influenced by probabilistic noise. Its application gives surprising new insights into the structure of the attractor of the stochastic Duffing-van der Pol oscillator. The resulting approximations sug-

gest that a stochastic perturbation of a system close to a Hopf bifurcation point can cause chaotic dynamics.

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**MS53****Relative Equilibria of Tethered Satellite Systems**

We study existence and stability of relative equilibria for a system of two satellites joined by a continuous tether. For circular orbits of the satellites we calculate all possible positions of the tether and their stability by means of the second variation of the amended potential. We focus on very stiff tethers and show that equations for relative equilibria and stability conditions are well approximated by the corresponding equations and conditions for an inextensible tether.

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**MS53****Nonlinear Dynamics of Tethered Satellite Systems**

The equations of motion of a tethered satellite system are highly nonlinear and the dynamics possesses many interesting features. The paper examines the stationkeeping phase first. It is noted that regions of both regular and chaotic motions exist for planar as well as three dimensional cases. The size of these regions depends on eccentricity and the value of the Hamiltonian. The deployment/retrieval phases are also considered. Amplitudes of limit cycle oscillations during controlled retrieval are determined.

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**MS53****Numerical Treatment of the Relative Equilibrium Equations**

The stability problem of relative equilibria requires first the calculation of the relative equilibria from a nonlinear boundary value problem. Second one has to check whether the amended potential of the configuration under investi-

gation has a minimum. Both approaches can be performed only numerically for practically relevant examples. Planar equilibria of tethered satellites are calculated by applying homotopy and collocation methods. The minimum property of the amended potential is shown by solving a generalized eigenvalue problem.

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**MS53****Modelling and Equations of Motion of Tethered Satellite Systems and Some Simulation Results**

The tether is modelled as a viscoelastic string and the satellites as rigid bodies, taking into account the possibility of deployment and retrieval of the tether. The equations of motion, derived from a variational principle for a specially selected set of variables, are a stiff system of nonlinear coupled partial and ordinary differential equations. Their numerical solution is explained and some simulation results of important operational processes, displaying unstable and chaotic dynamics are presented.

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**MS54****Underwater Vehicle Dynamics and Stabilization**

We present the dynamics of underwater vehicles following work of Leonard and Marsden and others. This problem involves the Euclidean symmetry group and the relevant reduction theory for mechanical systems with this symmetry is reviewed. Finally, work of Bloch, Leonard and Marsden on stabilization of Euler-Poincaré systems that is relevant to this problem will be presented.

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**MS54**  
**Validity, Structure and Universality of the Ginzburg-Landau Equations**

Bifurcations that take place in spatially-extended systems are believed to be governed by simpler ‘universal’ PDEs

known as Ginzburg-Landau equations. We will describe results on the validity, structure and universality of the Ginzburg-Landau equations. In particular, we show how the underlying Euclidean symmetry explains the universality (and lack thereof) of the Ginzburg-Landau equations.

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**MS54****Bifurcations and Dynamics of Spiral Waves**

Spiral waves and scroll waves arise in a variety of biological and chemical systems. These systems are often modeled by reaction-diffusion systems on the entire plane or the three-dimensional space. In this talk, recent efforts are described to understand transitions from spiral waves or scroll waves to more complex patterns utilizing only the underlying Euclidean symmetry. Examples include hypermeandering spirals, and scroll waves under periodic forcing.

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**MS55****Nonlinear Control Design for Turbocharged Diesel Engines**

A Control Lyapunov Function based method for robust nonlinear controller design is applied to a diesel engine equipped with a variable geometry turbocharger (VGT) and an exhaust valve recirculation (EGR) valve. VGT varies the turbine flow area to provide faster torque response. EGR valve allows controlled recirculation of exhaust gas into the intake manifold to reduce NO<sub>x</sub> emissions. This control design problem is characterized by significant interactions between the actuators and inherently nonlinear nature of the diesel engine. Performance of the closed loop system is illustrated by simulations and experimental data.

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**MS55****Theory and Application of Injection Locking**

Injection-locking is a process whereby the frequency of a autonomous system (oscillator) tracks the frequency of a periodic input signal. Although related to more familiar Phase-Locked Loops, the mechanism is a bit different and

offers significant performance and implementation advantages in certain applications. We will present a simple model of injection locking, give an example of numerical simulation of such systems in steady-state, then describe an application of the technique for a commercial integrated circuit.

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#### MS55

##### Analyzing Multi-Rate Dynamical Systems Using PDEs

Widely separated time scales arise in many physical systems, especially from electronics, e.g., switched-capacitor filters, mixers, voltage-controlled oscillators (VCOs), etc.. Computation of such systems is often difficult or impossible with available methods, especially when strong nonlinearities are also present. In this talk, we show how it is useful to reformulate such systems in terms of multiple time variables. Doing so transforms differential-algebraic equations (DAEs) to partial differential equations (PDEs) which are much easier to solve than the original DAEs themselves. We show that different multi-time formulations are useful for non-autonomous systems (e.g., mixers) and forced autonomous systems (e.g., VCOs). We also touch on how PDE formulations are useful for macromodelling linear time-varying and nonlinear systems.

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#### MS55

##### Input-Output Modeling of Nonlinear Components

I examine the system identification problem for driven nonlinear components especially as it relates to engineering applications. A framework for constructing measurement based black box models of nonlinear components is described based upon extensions of the Taken's embedding theorem. Practical procedure's for constructing models are illustrated to solve fundamental problems such as model and parameter selection. An outstanding problem of a nonlinear model reduction procedure for systems exhibiting large-time scale separations is also described.

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#### PS

##### Resonant Pattern Formation in a Reaction-Diffusion PDE System

A numerical study is performed to determine the pattern selection and evolution in a reaction-diffusion PDE system. For the classical Brusselator model the interaction between the reaction and diffusion terms can give birth to the well known rotating spiral waves. When the system is perturbed with a time-periodic forcing term, a spatial reor-

ganization is induced leading to various patterns. Depending on the forcing frequency, locked regimes i.e. standing wave patterns in the forms of labyrinths, fronts, etc are observed similar to the frequency-locked tongues of a driven nonlinear pendulum.

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#### PS

##### Elimination of quantization-Induced Limit Cycles in Nonlinear Dynamical Simulations

The use of digital computer simulations to gather probabilistic measures of nonlinear dynamical systems may result in incorrect results due to limit cycles induced by the discrete nature of the computer. This paper proposes the addition of low-level pseudo-random noise to eliminate such limit cycles. The amount of noise added and its effects, both theoretical and observed is examined.

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#### PS

##### Information Transmission Through Chaotic Modeling of Language

We propose a new way of communicating, based on the modeling of languages. The message to be sent is the symbolic sequence of a chaotic trajectory. Due to the use of a smart temporal partition, defined based on some statistic properties of the language, few or any interventions are required to target the trajectory in order to produce the aimed message. The message is encoded by transmitting to the receiver those targeting instructions.

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**PS****From High Dimensional Chaos to Stable Periodic Orbits: The Structure of Parameter Space**

Regions in the parameter space of chaotic systems that correspond to stable behavior are often referred to as windows. In this work, we elucidate the occurrence of such regions in higher dimensional chaotic systems. We describe the fundamental structure of these windows, and also indicate under what circumstances one can expect to find them. These results are applicable to systems that exhibit several positive Lyapunov exponents.

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**PS****A Study of a Forced Oscillator in an Electric Power System**

In power systems a harmful phenomenon known as ferroresonance can occur where over-voltages, over-currents and frequencies different than the frequency of the electric source can be generated. A particular power system has been modelled by seven non-linear, non-autonomous, stiff ordinary differential equations. The model has been investigated using non-linear dynamics techniques and numerical methods. Recent results will be shown.

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**PS****Optimal Targeting of Chaos**

Standard graph theoretic algorithms are applied to chaotic dynamical systems to identify orbits that are optimal relative to a prespecified cost function. Numerical experiments suggest that periodic saddle orbits of low period are typi-

cally less expensive to target (relative to a family of smooth cost functions) than periodic saddle orbits of high period

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**PS****On the Inverse Frobenius-Perron Problem (IFPP): Global Stabilization of Arbitrary Invariant Measures**

The inverse Frobenius-Perron problem (IFPP) is a global open-loop strategy to control chaos. The goal of our IFPP is to design a dynamical system in  $R^n$  which is: 1) nearby the original dynamical system, and 2) has a desired invariant density. We reduce the question of stabilizing an arbitrary invariant measure, to the question of a hyperplane intersecting a unit hyperbox; several controllability theorems follow. We present a generalization of Baker maps with an arbitrary grammar and whose F-P operator are the required stochastic

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**PS****Chaotic Choreography**

A symbol dynamics induced on a chaotic attractor can be used to generate choreographic variations. Movement sequences produced in this fashion are novel and interesting, but they occasionally violate the kinesiological or stylistic constraints that govern human motion. We solve this problem by building a graph-theoretic model of the joint movement patterns in a corpus of dances and using that model to construct *stylistically consonant* interpolation sequences to "smooth" abrupt transitions in the chaotic variation.

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**PS****Dynamics of the Four-Level Laser with Injected Signal**

A four level model of the laser with injected signal is considered. It is a more appropriate physical model than the two-level model. Eight equations describe the motion; how-

ever, the system is reduced to 3 equations by using adiabatic elimination of the polarization and centre manifold techniques. The bifurcation structure is analyzed and a comparison is made with the two level model.

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#### **PS**

#### **A Fractal Analysis of Electrotelluric Time Series**

The so-called electrotelluric potentials are the spontaneous electric self-potential of the ground. We have obtained electrotelluric potential registers from the state of Guerrero's coast during more than five years. These data sets constitute the so called electrotelluric time series. We show that the measuring of the fractal dimension by means of the Higuchi's method is appropriate; we study the temporal evolution of the fractal dimension and we discuss the feasibility of this method for to identify patterns that would be precursors of seisms with magnitude larger or equal than six.

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#### **PS**

#### **A Two-Dimensional Biofilm Model with Fingering Instabilities**

Biofilms are collections of microorganisms connected by polymer substances which form in the presence of flowing fluids. Biofilms have many properties of interest such as the spatial heterogeneity of typical biofilms. We present a two-dimensional biofilm model based on a simple model for viscous, two phase flow. The model will be used to

investigate the propagation of the biofilm-fluid interface. Results from numerical simulations of the equations are shown.

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#### **Identification of Decision Systems**

This paper considers the problem of developing quantitative models for decision systems based on observations of the input-output behavior of the systems. We begin by showing that a large class of decision systems can be modeled as dynamical systems, and introduce a definition for a (dynamical) decision system which is general enough to allow a wide range of decision phenomena to be modeled and yet retains sufficient structure to permit meaningful system identification problems to be posed and solved. We then present several algorithms for decision system identification and illustrate their use through implementation with decision policies designed using a variety of methods.

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#### **PS**

#### **Identification of Hybrid Dynamical Systems I: Theory**

This two part paper considers the problem of developing quantitative models for (uncertain) hybrid dynamical systems using measured data. We begin by introducing a definition for parameterized hybrid dynamical systems which is general enough to allow a wide range of systems to be modeled and yet retains sufficient structure to permit meaningful system identification problems to be posed and solved. We then present a new approach to hybrid system identification and illustrate its use through the development of several parameter identification algorithms. In a companion paper we demonstrate the effectiveness of both the hybrid system modeling framework and the identification algorithms through several case studies involving systems

of importance in applications.

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**PS**

**Optimal Chaos Control Through Reinforcement Learning**

A chaos control algorithm based on reinforcement learning is described that can be used for the stabilization of unstable periodic orbits as well as for targeting. No analytical description of the map nor knowledge of the location of the periodic orbits to be stabilized is required. Numerical tests for the logistic map, the Hénon map and a forced oscillator model for the heartbeat demonstrate good and fast performance of the algorithm also under noisy and nonstationary conditions.

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**PS**

**Chaotic Transitions and Low-Frequency Fluctuations in Semiconductor Lasers with Delayed Optical Feedback**

We investigate a single-mode semiconductor laser system pumped near threshold and subject to optical feedback. In particular, we study chaotic transitions leading to the low-frequency fluctuations (LFFs) by numerical integration of Lang-Kobayashi equations. We classify different types of chaotic transitions by computing bifurcation diagrams covering a wide range of feedback levels. Our computations suggest that LFFs can be either sustained or transient, depending on parameters of the system.

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**PS**

**Unstable Periodic Orbits and the Transition to High-Dimensional Chaos**

We study the transition to high-dimensional chaos (more than one positive Lyapunov exponent) by analyzing properties of unstable periodic orbits (UPOs) embedded in the chaotic attractor. Heuristic argument and explicit computation of UPOs for several high-dimensional maps suggest that the transition is usually accompanied by a type of non-hyperbolicity common in high-dimensional systems: unstable dimension variability. We argue that due to unstable dimension variability, subsequent Lyapunov exponents typically pass through zero smoothly from the negative side.

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**PS**

**A Variational Principle for the Amplitude of Limit Cycles**

The amplitude of limit cycles of Liénard type equations  $\ddot{x} + F(\dot{x}) + x = 0$ , for  $F(\dot{x})$  such that a single limit cycle exists can be obtained from a variational principle. We apply it to the Rayleigh-van der Pol equation to show explicitly how to recover some known results without resorting to perturbation theory.

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**PS**

**Unstable Periodic Orbits and the Natural Measure of Nonattracting Chaotic Saddles**

We investigate the characterization of the natural measure of nonattracting chaotic saddles by unstable periodic orbits embedded in the saddle. Results with the Hénon map for which periodic orbits can be enumerated lend credence to the conjecture that the unstable periodic-orbit theory of the natural measure is applicable to chaotic saddles, hyperbolic or nonhyperbolic. As a related problem, we investigate the scaling of the probability of experimentally detecting unstable periodic orbits embedded in chaotic saddle. We find, through heuristic theoretical argument and

systematic numerical experiments, that the probability typically decreases exponentially as the period increases with an exponent determined by the dynamical invariants of the chaotic saddle.

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#### PS

#### Controlling Transient Chaos in Deterministic Flows with Applications to Electrical Power Systems and Ecology

Transient chaos is a common phenomenon in nonlinear dynamics of many physical, biological, and engineering systems. In applications it is often desirable to maintain sustained chaos even in parameter regimes of transient chaos. We address how to sustain transient chaos in deterministic flows. We utilize a simple and practical method, based on extracting the fundamental dynamics from time series, to maintain chaos. The method can result in control of trajectories from almost all initial conditions in the original basin of the chaotic attractor from which transient chaos is created. We apply our method to three problems: (1) voltage collapse in electrical power systems; (2) species preservation in ecology; and (3) elimination of undesirable bursting behavior in a chemical reaction system.

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#### Dynamical Systems Methods for Geophysical and Environmental Modeling

In this talk, I will present the results on stochastic as well as deterministic dynamical systems methods for prototypical models in geophysical and environmental systems.

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#### PS

#### A Novel Measure of Nonstationarity in Dynamical

#### Systems

We use a concept from information theory, namely the *information flow* (IF), to measure qualitative changes in nonstationary dynamical systems. In several model simulations where parameter changes are imposed on the systems, we find that the IF can detect and predict accurately the onset of nonstationarity and/or the changes of dynamical behaviours (e.g. a reduction of dynamical "complexity"). In the context of the detection and prediction of dynamical events (e.g. mechanical failures, unstable laser emissions, neurophysiological diseases such as epileptic seizures or cardiac arrhythmia ...), we argue that the IF could serve as a characteristic *precursor* for the actual onset of the events. In the best of all possible worlds, knowledgeable ("therapeutic") dynamical intervention becomes possible.

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#### PS

#### The Breakdown of Shadowing in a Typical Physical System

The sinusoidally forced, damped, double pendulum is presented as a simple paradigm system that is unshadowable due to the presence in the attractor of periodic orbits that have different numbers of unstable directions. An argument is provided for the existence of parameter values where shadowing fails. Numerical simulations show attractors containing fixed points with different numbers of unstable directions. Finite-time Lyapunov exponents whose signs fluctuate, the hallmark of unshadowable systems, are also observed.

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#### Periodic Solutions of Neutral Functional Differential Equations: a Case Study

Bifurcation analysis of periodic solutions of neutral functional differential equations (NFDEs) faces a number of important new difficulties when compared with retarded

FDEs. The Poincaré operator is no longer a compact operator, instead it has both a point and an essential spectrum. We examine a specific example using a high-dimensional approximation combined with a numerical method that exploits the spectral properties to reduce the computational costs. Using these tools we show new dynamical phenomena (sensitivity to infinitesimal parameter changes, bifurcations of the essential spectrum) and raise a number of open theoretical questions.

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**PS**  
**Extracting Signals from Chaotic Laser Data**

Several experimental groups have demonstrated communication with chaotic lasers. Although the focus has not been on message security, it is believed that the dynamics typically lie on attractors of large dimension which may make it impossible to extract the hidden message using nonlinear forecasting techniques. In this paper, we analyze data from numerical simulations in order to determine what system information is necessary to make unmasking possible. We also comment on results using actual experimental data.

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**PS**  
**A Geometric Method for Calculating Diffusive Traveling Waves in Coupled Systems**

A geometric method to approximately find dispersive traveling waves of two coupled reaction diffusion equations is given. Finding these waves involves two distinct processes: finding a state space connection between critical points of the equation's nonlinearity, and finding a physical space traveling wave that takes values on the state space connection as a function of space and time. This paper describes a method that decouples these two processes in certain parameter regimes.

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**PS**  
**1:2 Resonance Mediated Transmission Band Gap Opening in a 1-d Nonlinear Discrete Periodic Medium**

We consider wave propagation in a nonlinear infinite diatomic chain of particles as a discrete model of propagation in a medium whose properties vary periodically in space. The particles have alternating masses  $M_1$  and  $M_2$  and interact in accordance to general nonlinear force  $F$  acting between the nearest neighbors. Using Fourier series methods and tools from bifurcation theory, we show that, for each 1:2 resonant wave-number  $k$ , there are two different frequencies  $\omega_{1,2}$ , such that the system admits nontrivial small-amplitude traveling wave solutions  $g$  and  $h$ , depending only on the linear combination  $z = kn - \omega_{1,2}t$ . We determine the nonlinear dispersion relations explicitly.

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**PS**  
**Correlation of Inhaled Formaldehyde Flux Predictions with Regional DNA-Protein Crosslink Measurements in Rat Nasal Passages**

DNA-protein crosslinks(DPX) are used as a dosimeter for inhaled formaldehyde and are associated in the presence of

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tumors in rat nasal passages. Using a physiologically-based pharmacokinetic model for uptake of formaldehyde and a 3-D computational fluid dynamics model of the rat nasal passages, we correlate mass flux and exposure concentration with DPX in two separate regions of the nose (high tumor and low tumor). We show that the mass flux, rather than the exposure concentration, is the dominant factor for the different lesion formation in these two regions.

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**PS****Identification of Hybrid Dynamical Systems II:  
 Case Studies**

This two part paper considers the problem of developing quantitative models for (uncertain) hybrid dynamical systems using measured data. In the first part we introduce a useful definition for parameterized hybrid dynamical systems and present a new approach for identifying these systems. In this part of the paper we illustrate the effectiveness of both the hybrid system modeling framework and the approach to system identification through several case studies taken from the field of intelligent control. Included among the example systems we study are a simple constrained robotic system, an automated highway system, and an electric power grid under supervisory control.

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**PS****Simulation of Socio - Economic Development in  
 Two Areas Competing for Scarce Resources in  
 Tenerife, Canary Islands**

On studying the recent development of tourism in Tenerife we will first have to consider the articulation of the two productive models: 'Market' and 'Tertiary' which coexisted largely in "harmony" until the accommodation supply boom on the southern side of Tenerife. Then it appears a structural Change and, after this explosion in the 80's, the Tertiary sector has almost completely displaced the importance of agricultural production. Therefore its entire socio-economic development may be understood purely as

a function of fluctuations in Tourist Demand, and its development in a limited environment involves a struggle for scarce resources in the localities receiving the yearly current of visitors. From this point of view, we have undertaken a simulation of this socio-economic evolution in the Orotava Valley and the area centering on the municipal councils of Arona and Adeje. A system of logistic type differential equations will be found to accurately model the development in demand flows, under the assumption the potential European market is distributed between these two tourist destinations in accordance with the laws of the Struggle for Scarce Resources. Having completed this simulation exercise successfully, it was found that this conceptual context may also be applied to the distribution of migratory flows between these two areas of the island. In this simulation the main problem deal with parameter identification, which will be solved with the aid of a new technique.

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**PS****Random and Deterministic Perturbation of a Class  
 of Skew-Product Systems**

This poster is about the stability of chaotic synchronized systems under random and deterministic perturbations. More precisely we study the stability properties of skew-product systems  $T(x, y) = (f(x), g(x, y))$  in which the contraction rates in  $g$  are non-uniform. We study the orbit stability and stability of mixing under deterministic and random perturbations of  $g$ . Our results also have applications to the stability of Iterated Function Systems which 'contract on average'.

**Keywords:** Skew-Products, Chaotic Synchronized Systems, Random Perturbations.

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**PS****Lie Transfer Map Propagation of Perturbed Kep-  
 lerian Systems**

Time evolution of a Hamiltonian system may be represented by a Lie transfer map. This map can be used to propagate a point in phase space from an initial time to some later time. As an example in celestial mechanics, consider an earth-orbiting satellite. Using a simple geopotential ( $J_2$ -perturbation only), we can do orbit predictions without numerical integration and without computing a normal form, the two traditional ways of propagating orbits.

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**PS****Boundary Effects on Complex Ginzburg-Landau Dynamics**

We study the effects of different types of walls at finite distance on spatiotemporally chaotic regimes of the two-dimensional complex Ginzburg-Landau equation. Dirichlet walls seem to have the greatest impact on the dynamics. In particular, target states become stabilized by them. Other phenomena, such as synchronization of boundary wave emission, entrainment by corners, and anchoring of defects by shock lines are also reported.

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**PS**  
**Mode Interactions of Globally-Coupled Phase Oscillators**

The onset of collective behavior in a population of  $N$  globally-coupled phase oscillators with randomly distributed frequencies is studied when there are competing synchronizing transitions at distinct mode numbers  $n > l \geq 1$ . In addition to the distribution of native frequencies, additive white noise is included in the phase equations to produce diffusion in the phases. For large  $N$ , the population is described by a kinetic equation and the normal form equations are derived by center manifold reduction. The resonant mode interaction with  $n = 2l$  is considered in detail for populations with couplings and frequency distributions that are reflection symmetric so that the model has  $O(2)$  symmetry.

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**PS**  
**Exponentially Long Equilibration Times in a 1-D Classical Gas**

The quantum mechanical ‘freezing out’ of the vibrational

degrees of freedom for a diatomic gas has a classical counterpart. We consider here a simple, general 1-D model of a classical gas, and show that when the vibrational and translational time scales are well separated, the collisional energy exchanges between the translational and the vibrational degrees of freedom are reduced by an exponential factor. We determine the time scale for the evolution towards statistical equilibrium.

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**PS**  
**Karhunen-Loeve Decomposition of Peripheral Blood Flow**

We first discuss the effect of embedding time ( $\tau$ ) and dimension ( $d$ ) on the Karhunen-Loeve decomposition of periodic scalar signals. When  $\tau \neq k/2f_i$  ( $f_i$  are characteristic frequencies of the signal and  $k$  is a positive integer),  $2n$  modes are obtained for a  $n$ -periodic signal. Secondly, we demonstrate that peripheral blood flow signal contains pairs of modes on a minute time scale. We interpret this result as an evidence that the flow of blood through the cardiovascular system is oscillatory.

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**PS**  
**Oscillatory Neurocomputers With Dynamic Connectivity**

Our study of thalamo-cortical systems suggests a new architecture for a neurocomputer that consists of high-frequency oscillators. We use Kuramoto’s model to illustrate the idea and to prove that such a neurocomputer has oscillatory associative properties. The advantage of such a neurocomputer is that it can be built using VCOs, MEMS, optical switches, Josephson junctions, macromolecules, or oscillators of any other kind.

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**PS****Phase Equations for Relaxation Oscillators**

We prove that dynamics of arbitrary weakly connected relaxation oscillators can be described by strongly connected phase equations. The phase model has discontinuity at the point corresponding to the in-phase synchronization. We show that many facts of the Fast Threshold Modulation theory developed by Kopell and Somers, such as super-convergence to the synchronized solution, its super-stability, etc., can easily follow from the form of the phase model.

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**PS****A Generalized Single Wave Model for Unstable Electrostatic Waves**

The nonlinear evolution of a unstable electrostatic wave is considered for a multiple-species Vlasov plasma. From the singularity structure of the associated amplitude equation, the asymptotic features of the electric field and distribution functions are studied in the weak growth rate limit. The asymptotic electric field is monochromatic at the wavelength of the linear mode with a nonlinear time-dependence. The structure of the distributions outside the resonant region is given by the linear eigenfunction but in the resonant region the distribution is nonlinear. This generally derived picture corresponds to the single wave model originally proposed by O'Neil, Winfrey and Malmberg for the special case of a cold-beam instability in a plasma of fixed ions. The "single wave" reduction of a multi-species Vlasov plasma supporting a weakly unstable electrostatic mode is implemented. The reduced model is a Hamiltonian system comprised of a nonlinear Vlasov equation describing the interaction of the resonant particles and the monochromatic electric field, and a reformulated Poisson's equation for the time-evolution of the electric field amplitude. We discretize the model and follow the evolution of an unstable wave numerically; special attention is paid to the scaling of wave amplitude with the linear growth rate.

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**PS**  
**Nonlinear Polarization Dynamics in Mode-Locked**

**Optical Fiber Lasers**

Lab experiments demonstrate that the addition of a passive polarizer in an optical fiber laser cavity can result in the generation of stable optical pulses. Propagation is modelled by coupled nonlinear Schrödinger equations, where the polarizer is treated as a periodic perturbation. Exploiting the variational nature of the equations, the dynamics of pulse solutions can be reduced to an ODE system for which we investigate existence of attracting states, bifurcation structures and stability.

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**PS**  
**Thin Liquid Films: Flows on an Imperfect Surface**

We use a recently developed numerical scheme in order to compute the flow of a thin film down an inclined surface, within the framework of lubrication approximation. It is found that small perturbations, which could be due to surface roughness, considerably influence the stability of the flow. Analysis of the importance of the involved lengthscales on the stability of the 1D film, as well as the preliminary results for full 2D problem are given.

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**PS**  
**The Multisymplectic Geometry and Variational Integrators for the Camassa-Holm Equation**

We show that for a partial differential equation with a second-order Lagrangian that the unique Cartan form naturally arises in the boundary term of the first variational principle. We prove the covariant Noether principle and the multisymplectic form formula. In the application to the Camassa-Holm equation, we derive a numerical integrator that manifestly conserves the discrete multisymplectic form, as well as, the discrete momentum mappings corresponding to symmetries of the equation.

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**PS**  
**Pulse Dynamics in Isotropic and Anisotropic Reaction-Diffusion Systems**

We study the dynamics of concentration pulses in a system of reaction-diffusion equations modeling catalytic CO oxidation on Pt(110). Stable pulses have been observed experimentally in this system through the construction of quasi one dimensional domains using microlithography. They have also been found computationally, and, as the model parameters vary, they undergo different types of instabilities (from modulated traveling waves to "backfiring" and spatiotemporal chaos). We perform a systematic study of the instabilities of these pulses in 1-D with a view towards determining the regions of existence of stable pulses and understanding the nature of the instabilities. We take advantage of software and mathematical results on global bifurcations to compute pulses as homoclinic orbits of a (three-dimensional) set of ODEs arising from the PDE in a traveling frame. Approximating the pulses by wavetrains of large wavelength, and discretizing the PDE in space we numerically approximate the spectrum of the pulses and compute their full PDE stability. We then proceed to examine the effects of anisotropy and surface heterogeneities on pulse dynamics. Comparisons with 2-D simulations as well as experimentally observed phenomena (from the work of Drs. Hartmann and Imbihl in Hannover) are also presented.

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**PS**  
**A Mathematical Model of True Polar Wander**

Inertial Interchange True Polar Wander has been suggested as a possible mechanism for rapid continental drift during the early Cambrian era. We have constructed a pedagogical model that captures the essential characteristics of the interchange event by averaging over daily rotations, incorporating a time-dependent moment of inertia tensor coupled to the rotational dynamics, and by including double bracket dissipation.

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**PS****Nonlinear Behavior of the Inner Ear**

We first decompose the auditory potentials of Mongolian gerbils into the cochlear microphonic (CM) and a compound action potential (N1). We then examine the instantaneous frequency  $\nu(t)$  of the CM. The function  $\nu$  is found to depend on both sound pressure level and frequency. It is substantially affected when the cochlea is damaged by exposure to noise. We give a physical interpretation of the instantaneous frequency and discuss the possibility of modelling the CM with (possibly coupled) nonlinear oscillators.

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**PS****Solitary-Wave Solutions of a Nonlinearly Dispersive Hamiltonian System**

The recent study of nonlinearly dispersive evolution equations from physical problems has demonstrated a variety of weak, non-analytic solitary wave solutions as limits of analytic solitary waves, similar to the case of the wave of extreme height in the full water wave problem. Investigating these equations has lead to the understanding of mathematical modeling. I will address these issues by comparing solitary wave solutions of a Hamiltonian system with those of the KdV equation.

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**PS****Stochastically Forced Navier-Stokes Equation**

We will discuss the long term dynamics of the stochastically forced Navier-Stokes equations. We will present results on the regularity of solutions and the structure of the random attractor under various assumptions. In particular, we will discuss settings under which the attractor has a simple structure and in which the system is ergodic. We will also make rigorous the idea that the system can be viewed as evolving on a finite dimensional phase space at the expense of giving the dynamics an infinite memory.

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**PS****Color Map of Lyapunov Exponents of Invariant Sets**

The largest Lyapunov exponent of the Lorenz system is used as a measure of chaotic behavior to construct parameter space color maps. In fact, the color map associates points in parameter space to Lyapunov exponent values of the invariant set. An obvious practical application is the use of the color map to alter and manipulate the dynamical state of the invariant set by following an approximately chosen path in parameter space.

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**PS****Dynamical Systems as Kolmogorov Data Compressors**

The Kolmogorov complexity of a sequence is the length of the shortest program on a Turing-complete machine that produces that sequence. A related concept is complexity/distortion theory, in which a sequence is to be approximated as closely as possible by a program. In general finding the shortest program to represent real data is impractical. However, by restricting attention to particular simple dynamical systems, "programs" with complexity/distortion approaching the Shannon rate/distortion bound can be found using feasible algorithms.

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**PS****Multiple Scales Averaging of Parametric Gain Equations with Periodic Domain Poling**

We perform a multiple scales averaging analysis of the parametric gain equations with a rapidly periodically poled nonlinear coefficient. This poling is shown to produce on average an effective cubic nonlinearity which slightly detunes the standard resonance criterion used in quasi-phase-matching theory. The use of asymmetric poling schemes to allow electrooptic tuning of quasi-phase-matched devices is also analysed. Numerical integration of the original equa-

tions shows good agreement with the averaged equations.

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**PS****Control and Synchronization of Spatially Extended Systems**

We investigate the problem of controlling and synchronizing spatially extended systems. For this purpose a new coupling scheme is introduced, that allows to control and synchronize the dynamics with only a few driving signals from local regions. As an application we estimate model parameters of partial differential equations from time series.

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**PS****Prediction of Spatio-Temporal Time Series Based on Reconstructed Local States**

The starting point for most analysis methods used in Nonlinear Time Series Analysis are measurements of a single observable of the system of interest. Many interesting dynamical systems, however, are spatially extended and thus any description using only a few local or global observables may be incomplete. Therefore, we presented an approach for analyzing and predicting spatio-temporal time series using reconstructed local states. As numerical examples the evolution of different hyperchaotic spatially extended systems is predicted from previously sampled data that are generated by a Kuramoto-Sivashinsky equation, a coupled map lattice and coupled nonlinear oscillators.

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**PS****The Hopf Fibration and its Applications**

Among the most important topological constructions are Hopf fibrations. That they both play an important role in topology itself and have numerous physical applications lends credence to this statement. In this talk, I will discuss some of these applications as motivation for mathematicians to learn about the physical significance of the Hopf fibration in greater detail than that presented here. I will focus my attention primarily on rigid body rotation and the Hopf fibration  $h : S^3 \rightarrow S^2$ .

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### PS

#### Complex Dynamics in the 1:3 Steady Mode Interaction

The dominant spatial resonance in Rayleigh-Bénard convection with periodic boundary conditions and midplane reflection symmetry is the 1:3 resonance. For low Prandtl numbers the normal form describing this steady-state interaction exhibits complex dynamics, including standing, traveling, and modulated traveling waves, as well as a heteroclinic connection between circles of standing waves and mixed states leading to chaotic dynamics of Shil'nikov type.

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### PS

#### Dispersion Relation and Oscillons in a Continuum Model for Vibrated Granular Media

A simple continuum model for thin layers of vertically vibrated granular media is discussed. The dynamical variables are the layer height and its vertically averaged horizontal velocity. In contrast to the usual Faraday waves the surface waves are excited non-resonantly. Within this framework the dispersion relation and the neutral curve for the onset of waves are closely connected and in quite good agreement with experiments. In the nonlinear regime one-dimensional oscillons are obtained.

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#### Filling the Rotation Interval at Discontinuous Bifurcations: A Continued Fraction

While studying the definite structured order by which periodic orbits occur in outer tangency bifurcation (see Ref. [1]), we also do a detailed study of the different rotation numbers involved. We find and derive a general continued fraction that describes not only our results but previous ones as well. We explain how this new continued fraction can be implemented to describe different discontinuous changes. [1] C. Robert, *et al.*, Phys. Rev. Lett. 80, 4867 (1998).

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#### Critical Exponents for Higher Dimensional Crises

As a system parameter is varied it is common for a chaotic attractor to be destroyed and be replaced by a chaotic transient (a crisis). The average duration of chaotic transients near crisis typically has a power law scaling. Little is known about critical exponents for these scalings in systems that have more than one positive Lyapunov exponent. We generalize previous theory to higher dimensional situations and test our formula using numerical experiments.

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#### 1-D Biofilm Models

A single species biofilm model is presented and the existence of steady state solutions is proved. This simple model, which does not include detachment, suggests that a steady state solution is possible if the inactivation rate is zero. It is also shown that a steady state solution corresponding to the absence of active biomass is linearly unstable provided the bulk substrate satisfies an inequality involving the observed decay rate. Other biofilm models will be presented and the behavior of possible steady state solutions of the models will be discussed.

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**PS****Possible Existence of Stochastic Resonances in Electrotelluric Time Series**

The aim of several studies focused on the earth crust, as a complex system, has been to find signals called "precursors" of earthquakes. A common method in this area is the electrotelluric time series analysis. This work presents some results of electrotelluric time series with data sampled at Acapulco station (Mexico) during 1995. This station is near the middle American trench. Our approach analyzes some non-linear properties using spectral methods. We detected frequencies of periodic signals whose behavior, as function of the average intensity of potential fluctuations, shows characteristics of stochastic resonances. This behaviour was observed some days before a M=7.4 earthquake.

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**PS****Big Islands in Dispersing Billiard-Like Potentials**

We derive a rigorous estimate of the size of islands (in both phase space and parameter space) appearing in smooth Hamiltonian approximations of two-dimensional scattering billiards. Thus, in this approximation, scattering molecules, having a smooth potential, give rise to non-ergodic motion. The derivation includes the construction of a local return map near singular periodic orbits for an arbitrary scattering billiard and for the general smooth billiard potentials, leading to *universality* classes for the local behavior.

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**PS****Libration Point Invariant Manifolds and Solar System Dynamics**

We present a simple model of the solar system using a series of planar circular restricted three-body systems. Numerical computations of libration point invariant manifold structures provide a starting point for understanding some dynamical processes within the solar system. As templates underlying the orbital dynamics, the invariant manifolds provide a simple explanation for some interesting phenomena; for example, comet resonance transitions, transport between the Kuiper belt and the asteroid belt, and zodiacal dust cloud structure.

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**PS****Markovian Analogue to Phase Transitions in Coupled Chaotic Map Lattices**

As a way of understand the processes that rule phase transitions (PTs) in diffusively coupled map lattices, we study the presence of PTs in coupled Markovian systems, and show that these PTs are similar to that found for chaotic maps by Miller and Huse. We present the phase diagrams of three dynamical systems, one chaotic and two Markovian, for square and triangle 2D lattices.

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**PS****Transition to High-dimensional Chaos in Coupled Oscillators**

Systems of coupled nonlinear oscillators often exhibit high-dimensional chaos, i.e., chaos with more than one positive Lyapunov exponent. We investigate how high-dimensional chaos arises in such systems. We find that as a system parameter changes, non-trivial Lyapunov exponents, except for the first one, pass through zero smoothly from the negative side. The relationship between these transitions and the local stability of the synchronization manifold is elucidated.

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**PS**  
**Modeling and Controlling Molecular Dynamics**

We present a model of laser control of molecular dynamics based on mixed-state quantum mechanics and discuss kinematical restrictions on the expectation values of quantum-mechanical observables and their implications. Illustrative computations for diatomic molecules show that it is possible to attain over 99% of the kinematical maximum of an observable, e.g. the energy of a molecular bond, energy level populations, etc., by driving the system with an optimal control. Algorithms for finding such controls numerically will be outlined.

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**PS**  
**Models for Insect Locomotion I: Dynamics and Stability in the Horizontal Plane**

We study the dynamics and stability of legged locomotion in the horizontal plane. Motivated by experimental studies, we develop two and three-degree-of-freedom rigid body models with both rigid "peg-legs" and pairs of elastic legs in intermittent contact with the ground. We consider prescribed leg displacements and conservative elastic leg models. The resulting piecewise-holonomic mechanical systems exhibit periodic gaits whose neutral and asymptotic stability characteristics are largely determined by geometrical criteria.

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**PS**  
**Matched Asymptotic Expansions and Smolder Combustion**

Smoldering combustion waves describe a solid/gas reaction moving through a porous medium. When the method of matched asymptotic expansions is used on the nonlinear PDEs which model the system, a closure problem arises. Solutions at the leading order depend on solutions at all other orders. One possible new approach to alleviate this problem is presented and applied to a model of smoldering combustion with the goal of describing the transition from smoldering to flaming.

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**PS**  
**Extraction of Teleseismic Signal Waveforms from Background Noise using Nonlinear Dynamic Forecasting**

This paper considers the use of nonlinear dynamic forecasting to detect and extract hidden teleseismic events representing distant nuclear test explosions from background seismic noise in a real data set collected by the Air Force Technical Application Center (AFTAC). The focus will be on using multistep forecasting methods to extract a faithful representation of the hidden teleseismic signal waveform. Effectiveness will be discussed relative to the signal-to-noise ratio of the hidden signal.

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**PS**  
**Cumulative Wavelength as a Source of Dynamical Information of the Molecular Gas Spectra**

The Problem of radiative transfer in the multicomponent gas mixtures with non-gray particles and boundaries is solved with a help of the Spectral Line-Based Weighted-Sum-of-Gray-Gases Model. The spectral parameters in this model were calculated using the new distribution function - cumulative wavelength, which allows efficient integration of the radiative transfer equation. Validation of the method is performed for mixtures of combustion gases with soot particles.

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**PS**  
**Average Expansion Rates and Dimension of**

### Strange Nonchaotic Attractors

We calculate the capacity dimension of strange nonchaotic attractors (SNAs) using a new method based on estimations of average expansion rates of the underlying dynamics. The example system used is a quasiperiodically forced circle map. With strong enough forcing, the dynamics of the system changes from two-frequency quasiperiodicity to a SNA. While the Lyapunov dimension is known to be one for this SNA, the capacity dimension is observed to change discontinuously from zero to a value close to two across the transition point.

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### PS

#### The Destruction of Horseshoes in 2D and 4D Symplectic Maps

We study the destruction of the horseshoes in symplectic maps using continuation from an anti-integrable limit. The anti-integrable theory provides a powerful dimension independent technique for obtaining analytical bounds on parameter ranges where horseshoes exists. Using a numerical continuation method, we follow orbits from their anti-integrable limit to the bifurcation where they are created. In particular, we study the family of homoclinic orbits whose birth is responsible for the destruction of the horseshoe.

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#### Fractal Dimension in Higher-Dimensional Chaotic Scattering Systems

We have tested a conjecture which gives formulas relating the dimension of invariant manifolds in "typical" chaotic scattering systems to average dynamical quantities. A three degree of freedom system will be described and formulas for the dimension of the stable manifold of the chaotic saddle presented. These formulas, along with numerical simulations, confirm the conjecture. The notion of "typical" is explained, and new insight is gained into the nature of atypicality.

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### PS

#### Microextensive Chaos of a Spatially Extended System

By numerically simulating the one-dimensional Kuramoto-Sivashinsky equation with rigid boundary conditions over the range  $80 \leq L \leq 90$ , we show that the Lyapunov fractal dimension  $D$  shows "microextensive" scaling in that  $D$  increases linearly with system size  $L$  even for increments  $\delta L$  that are small compared to the characteristic cell size of about 9. This suggests that the extensive increase in dimension with system size is not related to the appearance of new linearly unstable modes.

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### PS

#### Symbolic Analysis of Non-Stationary Time Series

Symbolic time series methods (where one converts an analog signal into a discrete one via severe coarse graining) have been successful in applications to many traditional problems in stationary time series analysis. For example: the detection of patterns, estimation of correlation timescales, discrimination, and parameter estimation. In this poster we will discuss the extension of these methods to weakly non-stationary systems with particular emphasis on the early detection of bifurcation precursors.

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### PS

#### Particle Dynamics and Mixing in the Frequency Driven Kelvin Cat Eyes Flow

Particle dynamics, mixing and transport in multi-frequency driven Kelvin cat eyes flow is studied. The Topological Approximation Method (TAM) is implemented to quantify mixing and transport. This investigation is re-

lated to a more general study of acoustically driven spray combustors. When multi-frequency forcing is applied to the fuel injector nozzles of a combustor, considerable improvements in mixing of the fuel droplets is expected thereby influencing the efficiency of the combustor.

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**PS****Binary Fluid Convection as a 2x2 Matrix Problem**

Eigenvalues of 2x2 matrices undergo either avoided crossing or complex coalescence, depending on sign of coupling (product of off-diagonal terms). Convection driven by competing thermal and concentration gradients can be viewed as the superposition of pure thermal and solutal problems, with coupling proportional to separation parameter. Surprisingly, both nonlinear convection amplitude and eigenvalues governing stability can be interpreted this way. Hopf and saddle-node bifurcations both result from complex coalescence due to negative coupling.

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**PS****Synchronization and Communication using Chaotic Frequency Modulation**

In this paper we propose a chaotic frequency modulation (CFM) technique for spread spectrum communications. Existence and stability of the synchronous mode is demonstrated analytically and numerically. Unlike synchronization of two conventional chaotic oscillators via FM channel, the proposed method provides selectivity with respect to interference *within* the frequency range of chaotic frequency oscillations. This method can be a viable alternative to the recently proposed "interpolated" frequency hopping for spread spectrum communications.

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**PS****Symmetry-Breaking of Eddies in Expanding Flows**

Incompressible flows at a moderate Reynolds number in a symmetrically expanding two-dimensional channel exhibit a pitch-fork bifurcation, as Reynolds number increases,

from a symmetric pattern of separated eddies into asymmetric patterns. A simple averaged equation that captures the transition is constructed, extending the boundary layer equations which develops singularities at separation points. The new averaged equation will be helpful in further studies of separated flows and free-surface flows that exhibit transitions in their flow patterns.

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**PS****Bifurcation and Dynamics of a Simple Power System Model**

Large scale power networks can be modelled effectively using either an ODE or DAE representation. The dynamics of a small model power system are investigated using numerical techniques. Interesting new features of the bifurcation structure of this model are presented, including a Bogdanov-Takens point, and the implications for real networks are discussed.

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**PS****Horseshoes in Two-Degree-of-Freedom Hamiltonian Systems with Saddle-Centers**

We consider a class of two-degree-of-freedom Hamiltonian systems which have saddle-centers with homoclinic orbits and do not take the form of small perturbations of integrable systems. Using a Melnikov-type global perturbation technique, we present a criterion for the existence of horseshoes in their dynamics on energy level sets near ones of the saddle-centers. It is especially remarkable that the criterion is very similar to that for the existence of transverse homoclinic orbits to resonant periodic orbits in dissipative, time-periodic perturbations of the Hamiltonian systems. We also give an example for the undamped, coupled Duffing oscillators to demonstrate the theory.

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**PS****Diffusion in Action Space for Weakly Nonintegrable Hamiltonian Systems**

Starting from the Liouville equation for the single-particle phase-space distribution of a weakly nonintegrable Hamiltonian system, the coarse-grained distribution function of action variables is studied by means of projection operator. It is shown that this coarse-grained distribution function is governed by a kinetic equation similar to the Fokker-Planck equation but with memory integral. For localized

nonlinear perturbations, this kinetic equation can be reduced to a functional map. Further approximation leads to a moment map which can be iterated numerically for studying action dynamics.

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**PS**  
**Distributions of Rotation Numbers**

The main object of study for chaotic circle maps is the interval of rotations numbers. This interval carries a lot of information about the existence of orbits. We investigate the rotation interval from the perspective of the likelihood of orbits with given rotation numbers and define the "distribution of rotation numbers". Even though rotations numbers of individual orbits cannot be calculated, we show that this distribution can be approximated numerically and compute it for examples.

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**PS**  
**Forecasting High Waters at Venice Lagoon using Chaos Theory Techniques**

Time series analysis using non-linear dynamics systems theory has been applied to water level data recorded every hour at "Punta della Salute" Venice Lagoon during 1980-1994. The results based on the reconstruction of the state space using the embedding theorem are presented. Moreover, a local look-up model based on the dynamic dimension, has been used to estimate the evolution of the system as well as the predictability limits.

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**PS****Wavelet Approach to Hamiltonian Problems**

We present applications of the methods from wavelet analysis to a number of Hamiltonian problems and their perturbations, KAM problems, quantization problems. We consider dynamical problems in invariant variational approach via coadjoint orbit picture, semiproducts and metaplectic structure. We construct symplectic, Poisson and quasi-complex structures using generalized wavelets and non-standard representations for operators in wavelet bases (coherent, well localized) in functional spaces or scale of spaces. We consider applications of our approach to the theory of homoclinic chaos, renormalization group calculations and quasiclassics.

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**PS**  
**Subsystem Recurrences in High-dimensional Chaotic Systems**

By estimating low-period UPOs using near recurrences in short time-series, we show that the number  $N_R$  of recurrences scales as  $\epsilon^{D_{NR}}$  with recurrence radius  $\epsilon$ , where  $D_{NR}$  is a recurrence dimension. Using the Kuramoto-Sivashinsky equation, we demonstrate that the probability of finding recurrences in nearby subsystems is not independent. This suggests that extensive chaotic systems should not be interpreted as being made up of weakly coupled independent subsystems.

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# APPLICATIONS of DYNAMICAL SYSTEMS

May 23-27, 1999

Snowbird Ski and Summer Resort • Snowbird, Utah



# **SIAM EVENTS**

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# **2000**

## **Eleventh ACM-SIAM Symposium on DISCRETE ALGORITHMS (SODA 2000)**

**January 9-11, 2000**

Holiday Inn Golden Gateway Hotel • San Francisco, California

*Sponsored by ACM-SIGACT and SIAM/DM*

Organizer: David B. Shmoys, Cornell University

**Abstract deadline: July 13, 1999**

## **Eighth International Conference on NUMERICAL COMBUSTION**

**March 5-8, 2000**

Amelia Island Plantation • Amelia Island, Florida

*Conducted by SIAM in cooperation with INRIA*

Organizers: John D. Buckmaster and D. Scott Stewart, *University of Illinois, Urbana-Champaign*; Mitchell Smooke, *Yale University*

**Abstract deadline: September 15, 1999**

## **Third SIAM Conference on MATHEMATICAL ASPECTS of MATERIALS SCIENCE**

**May 21-24, 2000**

Crown Plaza Hotel • Philadelphia, Pennsylvania

Organizers: Richard D. James, *University of Minnesota, Minneapolis*; and Geoffrey B. McFadden, *National Institute of Standards and Technology*

**Abstract deadline: December 15, 1999**

## **Tenth SIAM Conference on DISCRETE MATHEMATICS**

**June 12-15, 2000**

Radisson Metrodome Hotel • Minneapolis, Minnesota

*Sponsored by SIAM Activity Group on Discrete Mathematics*

Organizer: Carla D. Savage, *North Carolina State University*

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 Marsden, Jerrold, ..... MS4, Sun. AM  
 Marsden, Jerrold E., ..... MS45, Wed AM  
 Matias, Manuel A., ..... CP27, Tues. PM  
 Matkowsky, B. J., ..... MS51, Thur. AM  
 Mattingly, Jonathan C., ..... PS, Wed PM  
 McLaughlin, Stephen, ..... MS31, Tues AM  
 McWilliams, James C., ..... MS37, Wed. AM  
 Meacham, Stephen P., ..... CP15, Tues. PM  
 Meiss, James D., ..... CP14, Mon. PM  
 Melbourne, Ian, ..... MS54, Thur. AM  
 Melville, Robert, ..... MS55, Thur. AM  
 Menon, Govind, ..... CP34, Tues. PM  
 Mezic, Igor, ..... CP23, Tues. PM  
 Michiels, Wim, ..... CP13, Mon. PM  
 Mikhailov, Alexander S., ..... MS14, Mon AM  
 Mindlin, Gabriel B., ..... MS32, Tues. AM  
 Mischaikow, K., ..... MS52, Thur. AM  
 Mischaikow, K., ..... CP37, Wed PM  
 Misiolek, Gerard, ..... MS45, Wed AM  
 Misra, A.K., ..... MS53, Thur. AM  
 Mitkov, Igor, ..... MS43, Wed. AM  
 Miura, Robert M., ..... CP1, Sun. PM  
 Moehlis, Jeff, ..... CP5, Sun. PM  
 Molnar, Peter, ..... CP29, Tues. PM  
 Moniz, Linda, ..... CP30, Tues. PM  
 Montaldi, James, ..... MS4, Sun. AM  
 Monti, Marco, ..... PS, Wed PM  
 Moon, Todd K., ..... PS, Wed. PM  
 Moore, Richard O., ..... PS, Wed. PM  
 Mordukhovich, Boris, ..... CP32, Tues PM  
 Morse, David, ..... MS19, Mon. AM  
 Moss, Frank, ..... MS47, Thur. AM  
 Muldoon, Mark R., ..... MS31, Tues AM  
 Muratov, Cyrill, ..... MS19, Mon. AM  
 Murray, Rua, ..... CP23, Tues. PM

**N**

Nadiga, B.T., ..... CP10, Mon. PM  
 Nagel, Sidney R., ..... MS27, Tues AM  
 Nakaki, Tatsuyuki, ..... CP43, Wed. PM  
 Namachchivaya, N. Sri, ..... MS1, Sun AM  
 Netoff, Tay, ..... CP1, Sun. PM  
 Neiman, Alexander, ..... CP41, Wed PM  
 Newton, Paul K., ..... MS4, Sun. AM  
 Nicol, Matthew, ..... MS44, Wed. AM  
 Nicolaenko, Basil, ..... MS49, Thurs AM  
 Nishikawa, Takashi, ..... CP25, Tues. PM  
 Nitsche, Monika, ..... CP43, Wed. PM  
 Nordmark, Arne B., ..... MS38, Wed. AM  
 Novick-Cohen, Amy, ..... CP37, Wed. PM  
 Novikov, Serguei P., ..... MS12, Mon. AM  
 Nussbaum, Roger D., ..... MS1, Sun AM

**O**

Ochs, Gunter, ..... MS52, Thur. AM  
 Odyniec, Michal, ..... MS50, Thur. AM  
 Olmsted, Dr Peter D., ..... CP44, Wed. PM  
 Oprea, Iuliana, ..... CP10, Mon. PM  
 Or-Guil, Michal, ..... CP18, Tues. PM  
 Ortiz, Michael, ..... IP6, Tues PM  
 Osinga, Hinke, ..... CP7, Sun. PM  
 Osipchuk, Marina, ..... CP29, Tues. PM  
 Ott, Edward, ..... MS48, Thur. AM  
 Owen, Markus R., ..... CP12, Mon. PM

**P**

Palacios, Antonio, ..... CP42, Wed, PM  
 Palus, Dr. Milan, ..... CP25, Tues. PM  
 Pan, Xingbin, ..... MS30, Tues. AM  
 Parekh, Nita, ..... MS14, Mon. AM  
 Parker, Ian, ..... MS43, Wed. AM  
 Parlitz, Ulrich, ..... PS, Wed. PM  
 Parlitz, Ulrich, ..... MS31, Tues AM  
 Partick, George, W., ..... MS35, Tues AM  
 Patil, Dhanurjay, ..... CP39, Wed PM  
 Peacock, Thomas, ..... CP19, Tues. PM  
 Peckham, Bruce B., ..... CP5, Sun. PM  
 Pecora, Lou, ..... CP39, Wed. PM  
 Pekarsky, Sergey, ..... MS45, Wed AM  
 Pikovsky, Arkady, ..... MS39, Wed. AM  
 Piro, Oreste, ..... CP23, Tues. PM  
 Pismen, Len, ..... CP8, Sun PM  
 Pojman, John A., ..... MS51, Thur. AM  
 Ponce, Gustavo, ..... MS24, Mon. PM  
 Porter, Jeff, ..... PS, Wed. PM  
 Porter, Mason A., ..... PS, Wed. PM  
 Posch, Harald, A., ..... MS25, Mon PM

Pourbohloul, Babak, ..... CP29, Tues. PM  
 Pourbohloul, Babak, ..... PS, Wed. PM  
 Pritchett, L.A., ..... PS, Wed PM

**Q**

Quinn, D. Dane, ..... CP4, Sun. PM

**R**

Rabinovich, Mikhail I., ..... CP1, Sun. PM  
 Ramírez-Rojas, Alejandro, ..... PS, Wed. PM  
 Rand, Richard H., ..... MS49, Thurs AM  
 Raquepas, Joe, ..... MS43, Wed. AM  
 Rasmussen, Kim, ..... CP31, Tues. PM  
 Ren, Xiaofeng, ..... CP24, Tues PM  
 Rey, Alejandro, ..... MS19, Mon. AM  
 Riecke, Hermann, ..... PS, Wed. PM  
 Riecke, Hermann, ..... MS7, Sun AM  
 Robbins, Kay A., ..... CP4, Sun. PM  
 Robert, Carl, ..... CP20, Tues. PM  
 Robert, Carl, ..... PS, Wed. PM  
 Roberts, Mark, ..... MS35, Tues AM  
 Robins, Vanessa, ..... CP25, Tues. PM  
 Rom-Kedar, Vered, ..... CP23, Tues. PM  
 Rom-Kedar, Vered, ..... PS, Wed. PM  
 Rosa Jr., Epaminondas, ..... MS11, Mon AM  
 Rosa Jr., Epaminondas, ..... CP36, Wed PM  
 Rosenblum, Michail, ..... CP41, Wed PM  
 Ross, Shane D., ..... PS, Wed. PM  
 Rotariu, A.I., ..... CP21, Tues. PM  
 Rottshafer, Vivi, ..... CP42, Wed. PM  
 Rousseau, Guillaume, ..... CP43, Wed. PM  
 Roy, Rajarshi, ..... MS1, Sun. AM  
 Roy, Rajarshi, ..... MS21, Mon. PM  
 Roy, Rajarshi, ..... MS11, Mon AM  
 Roychowdhury, Jaijeet, ..... MS55, Wed. AM  
 Ruan, Shigui, ..... CP16, Tues PM  
 Rubin, Jonathan E., ..... CP6, Sun. PM  
 Rubin, Jonathan E., ..... CP26, Tues PM  
 Rucklidge, A.M., ..... CP28, Tues. PM  
 Rulkov, Nikolai F., ..... CP1, Sun PM  
 Ryabov, Vladimir B., ..... CP9, Sun. PM

**S**

Sander, Evelyn, ..... CP37, Wed. AM  
 Sandstede, Bjorn, ..... MS54, Thur. AM  
 Sandstede, Bjorn, ..... MS42, Wed AM  
 Sanjuan, Miguel A. F., ..... MS48, Thur. AM  
 Sansour, Carlo, ..... MS10, Sun. AM  
 Santoboni, Giovanni, ..... CP3, Sun. PM  
 Sastre, Francisco, ..... PS, Wed. PM  
 Satija, Indu, ..... MS39, Wed. AM

Sauer, Timothy D., ..... MS26, Tues. AM  
 Sauter, Lonnie, ..... PS, Wed. PM  
 Schaaf, Renate, ..... CP34, Tues PM  
 Schiff, Steven J., ..... MS13, Mon AM  
 Schirmer, Sonja G., ..... PS, Wed. PM  
 Schmitt, John, ..... PS, Wed. PM  
 Schreiber, Sebastian J., ..... CP16, Tues. PM  
 Schreiber, Thomas, ..... MS3, Sun AM  
 Schult, Daniel A., ..... PS, Wed. PM  
 Schumaker, Mark F., ..... MS34, Tues AM  
 Schwartz, Ira B., ..... CP17, Tues. PM  
 Selgrade, James F., ..... CP16, Tues. PM  
 Setayeshgar, Sima, ..... CP18, Tues. PM  
 Shamolin, Maxim V., ..... CP14, Mon. PM  
 Shi, Junping, ..... CP8, Sun. PM  
 Shinbrot, Troy, ..... CP11, Mon. PM  
 Shkoller, Steve, ..... MS45, Wed AM  
 Short, Kevin M., ..... CP3, Sun. PM  
 Short, Kevin M., ..... CP35, Wed. PM  
 Short, Kevin M., ..... PS, Wed. PM  
 Showalter, Kenneth, ..... MS21, Mon. PM  
 Shygimaga, Dmytro V., ..... CP17, Tues. PM  
 Sideris, Thomas C., ..... MS24, Mon PM  
 Sidorov, Denis N., ..... PS, Wed PM  
 Sigeti, David E., ..... CP30, Tues. PM  
 Silber, Mary, ..... CP28, Tues. PM  
 Skeel, R. D., ..... CP22, Tues. PM  
 Smith, Terence R., ..... MS24, Mon. PM  
 So, Paul, ..... PS, Wed. PM  
 So, Paul, ..... MS36, Wed AM  
 Soloviov, Vladimir P., ..... PS, Wed. PM  
 Spradlin, Gregory S., ..... MS8, Sun AM  
 Stark, Jaroslav, ..... MS44, Wed. AM  
 Stark, Jaroslav, ..... CP41, Wed PM  
 Starke, Jens, ..... CP19, Tues. PM  
 Stefanovska, Aneta, ..... CP12, Mon. PM  
 Steindl, Alois, ..... MS10, Sun. AM  
 Steindl, Alois, ..... MS53, Thur. AM  
 Stepan, Gabor, ..... CP20, Tues. PM  
 Sterling, David G., ..... PS, Wed PM  
 Strogatz, Steven H., ..... MS22, Mon. PM  
 Subbarao, D., ..... CP31, Tues. PM  
 Sung, Myong-Hee, ..... CP22, Tues. PM  
 Sushchik, Mikhail M., ..... CP27, Tues. PM  
 Sweet, David, ..... PS, Wed. PM  
 Szwaj, Christophe, ..... CP36, Wed. PM

**T**

Taherion, Saeed, ..... CP17, Tues. PM  
 Tajima, Shigeyuki, ..... PS, Wed. PM

Tass, Peter, ..... MS47, Thur. AM  
 Tel, Tamas, ..... MS48, Thur. AM  
 Tempkin, Joshua A., ..... CP30, Tues. PM  
 Tenreiro, Eugenio Gutierrez, ..... CP9, Sun. PM  
 Terman, David, ..... MS29, Tues. AM  
 Terry, John R., ..... CP20, Tues. PM  
 Timmer, Jens, ..... CP6, Sun. PM  
 Timmer, Jens, ..... MS13, Mon. AM  
 Titi, Edriss, ..... MS10, Sun. AM  
 Topping, Peter, ..... MS45, Wed AM  
 Torre, Francisco Cervantes-De la, ..... PS, Wed. PM  
 Tovbis, Alexander, ..... MS18, Mon. AM  
 Tracy, E. R., ..... PS, Wed. PM  
 Tredicce, Jorge R., ..... MS32, Tues. AM  
 Triandaf, Ioana, ..... CP19, Tues. PM  
 Troger, Hans, ..... MS53, Thur. AM  
 Tsarin, Yury A., ..... CP36, Wed. PM  
 Tsega, Yamlak, ..... PS, Wed. PM  
 Tsujikawa, Tohru, ..... CP28, Tues. PM  
 Tuckerman, Laurette, ..... CP2, Sun. PM  
 Tuckerman, Laurette, ..... PS, Wed. PM  
 Tuffillaro, Nicholas B., ..... MS55, Thur. AM

**U**

None

**V**

Valente, Andre Xavier C. N., ..... CP9, Sun. PM  
 van der Heijden, G. H. M., ..... CP39, Wed. PM  
 Van Vleck, Erik S., ..... CP37, Wed PM  
 Varona, Pablo, ..... CP12, Mon. PM  
 Veen, Lennaert van, ..... CP10, Mon. PM  
 Venkataramani, Shankar C., ..... MS28, Tues. AM  
 Verhulst, Ferdinand, ..... CP10, Mon. PM  
 Vishnevskii, Mikhail, ..... CP34, Tues. PM  
 Volkovskii, A. R., ..... PS, Wed. PM  
 Vollmer, Jurgen, ..... MS25, Mon. PM  
 Volpert, V.A., ..... MS51, Thur. AM  
 Voss, H., ..... MS46, Thur. AM

**W**

Walkden, Charles, ..... MS6, Sun. AM  
 Walkenstein, Jonathan A., ..... CP40, Wed. PM  
 Walker, David M., ..... MS5, Sun. AM  
 Walsh, James A., ..... MS41, Wed AM  
 Wang, Don, ..... MS6, Sun. AM  
 Wang, Qi, ..... CP44, Wed. PM  
 Wang, Shouhong, ..... CP34, Tues. PM  
 Wang, Xiaoming, ..... MS28, Tues AM  
 Warnock, Robert L., ..... CP40, Wed. PM  
 Watanabe, Shinya, ..... PS, Wed. PM

Watts, Duncan J., ..... MS22, Mon. PM  
 Wei, Juncheng, ..... MS30, Tues. AM  
 Wiesel, William E., ..... CP14, Mon. PM  
 Wiggins, Chris H., ..... CP26, Tues. PM  
 Wilber, J. Patrick, ..... CP24, Tues. PM  
 Wilkinson, Amie, ..... MS6, Sun. AM  
 Williams, Chris, ..... MS31, Tues. AM  
 Wilson, Jon P., ..... PS, Wed. PM  
 Witt, Annette, ..... MS3, Sun. AM  
 Wittenberg, Ralf W., ..... MS14, Mon. AM  
 Wojtkowski, Maciej, ..... MS25, Mon. PM  
 Wriggers, Peter, ..... MS16, Mon. AM

**X**

Xia, Zhihong Jeff, ..... IP10, Thurs PM

**Y**

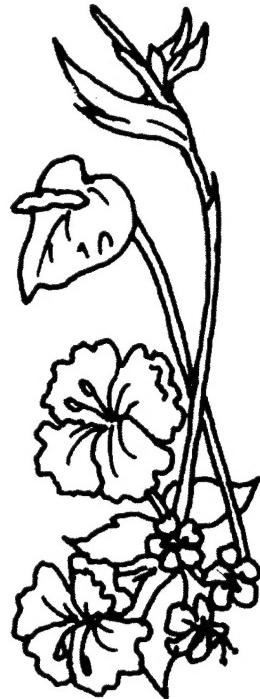
Yagasaki, Kazuyuki, ..... CP7, Sun. PM  
 Yagasaki, Kazuyuki, ..... PS, Wed. PM  
 Yang, Jianke, ..... CP21, Tues. PM  
 Yang, Tian-Shiang, ..... CP31, Tues. PM  
 Yao, Demin, ..... PS, Wed PM  
 Yeung, M. K. Stephen, ..... CP27, Tues. PM  
 Yew, Alice C., ..... CP21, Tues. PM  
 Young, Lai-Sang, ..... IP2, Sun PM  
 Yorke, James A., ..... MS38, Wed. AM  
 Yorke, James A., ..... MS26, Tues AM  
 Yoshikawa, Toshio, ..... CP2, Sun. PM  
 Young, Todd Ray, ..... PS, Wed. PM  
 Yuan, Guo-Cheng, ..... CP33, Tues. PM

**Z**

Zaks, Michael A., ..... MS39, Wed. AM  
 Zaldivar, Jose M., ..... CP26, Tues. PM  
 Zaldivar, Jose M., ..... CP35, Wed. PM  
 Zaldivar, Jose M., ..... PS, Wed. PM  
 Zapert, Radoslaw, ..... CP35, Wed. PM  
 Zegeling, P. A., ..... CP32, Tues. PM  
 Zeitlin, Michael, ..... PS, Wed. PM  
 Zeitlin, Michael, ..... CP40, Wed. PM  
 Zeng, Chongchun, ..... MS30, Tues. AM  
 Zgliczynski, Piotr, ..... CP22, Tues. PM  
 Zharnitsky, Vadim, ..... MS18, Mon. AM  
 Zharnitsky, Vadim, ..... CP31, Tues. PM  
 Zhou, Hong, ..... CP44, Wed. PM  
 Zoldi, Scott M., ..... PS, Wed. PM  
 Zoldi, Scott M., ..... MS14, Mon. AM  
 Zou, Xingfu, ..... MS1, Sun. AM

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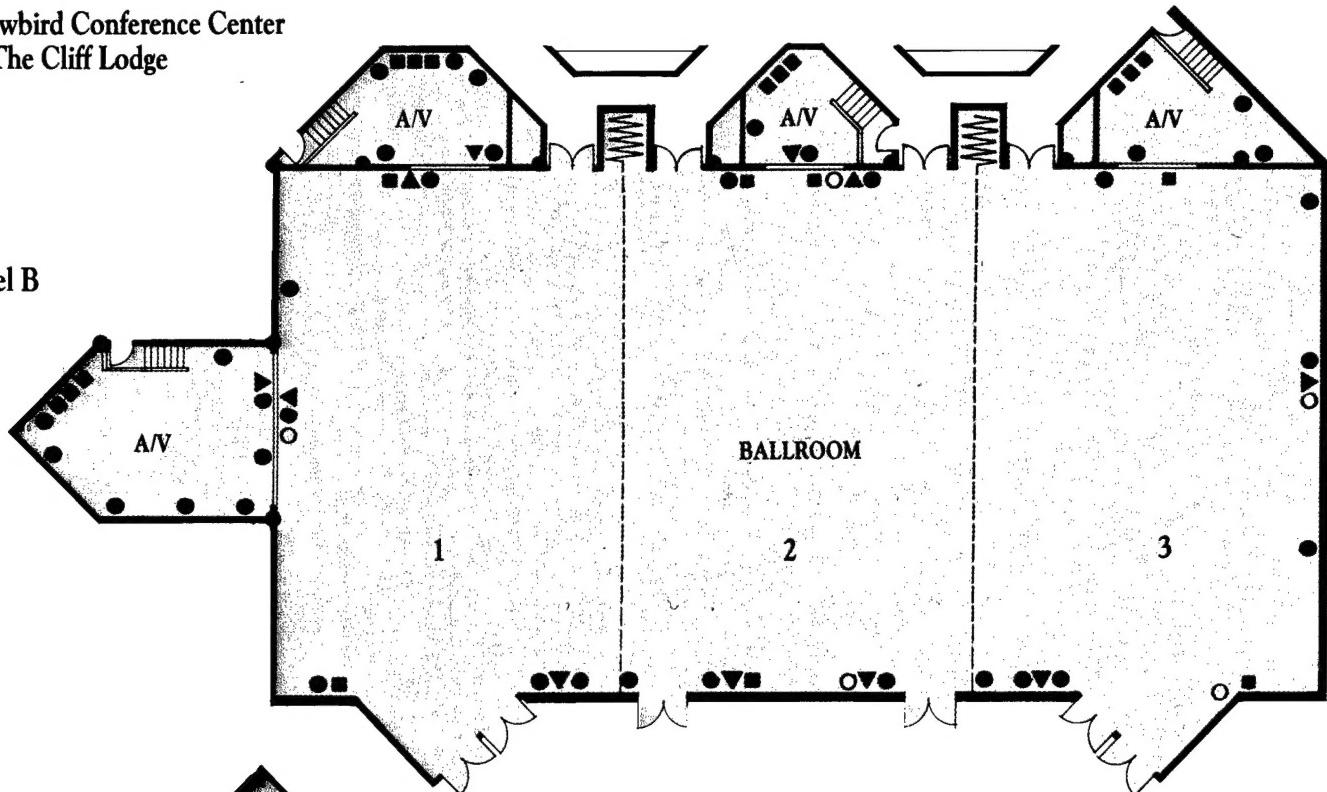
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